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Master's Degree Thesis

The Application of the United Nations Framework Classification for Resources to Piampaludo's Titanium Deposits in Liguria, Italy

A Case Study

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Abstract

The concept of sustainable development has evolved to actuality. Its practice has been firmly activated through the 2030 Agenda for Sustainable Development. Energy and raw materials have become as vital as air and water in present times; they are the source behind society's improved living standards. Effective production and supply of resource commodities are fundamental for achieving the Sustainable Development Goals (SDGs). Resource demand is significantly increasing with the current fast-growing population. Securing the required supply of mineral raw materials in a sustainable matter has developed as a dire challenge in the face of the mining industry. The entire value chain of raw material production generates significant damage to the environment, from emissions to biodiversity. In recent times, the mining sector has been improving to sustainably produce of mineral resources, yet stakeholders support further improvement.

The energy transition from hydrocarbons to green, clean energy is a key point for the 2030 Agenda. In order to trigger this transition, high productions of minerals are required, specifically Critical Raw Materials (CRMs). CRMs are the building blocks for a green technological progress towards a sustainable future. The production and supply of minerals strongly depend on their deposits, either as reserves or resources. Mineral deposits are identified and assessed on the basis of mineral's quantity and quality, whereas their development and excavation are determined by the technical feasibility as well as the environmental-socio-economic viability. These aspects are properly incorporated in the United Nations Framework Classification for Resources (UNFC).

UNFC is a principles-based and project-based comprehensive reporting tool for resource management that integrates, at its core, sustainability aspects with respect to the 2030 Agenda. UNFC is built on three critical pillars: the environmental-socio-economic viability (E axis), technical feasibility (F axis), and degree of confidence in the estimate (G axis). This tool has emerged from the need for a universally accepted reporting system to evaluate available resources. UNFC is designed to highlight the development status of a resource project for national, regional, and global reporting scopes while including different types of information. UNFC is a robust, coherent, and simple numerical coding system that can be applied to all

energy and raw material resources. It serves governments and other stakeholders in understanding the potentiality of their sources by providing sufficient data that facilitate decision-making. Within the mining sector, UNFC is adaptable to a wide range of projects, from operating mines, prospects, undeveloped resources, to historical estimates.

The Piampaludo Titanium deposits case study presented in this thesis demonstrates how UNFC can be applied to highlight project status along with the related environmental and social contingencies. The case study aims to rethink and strengthen the resource management sector in Italy. The integrated Titanium and associated metal deposits at the Piampaludo site have potential to improve the development of the Italian mining industry and with it the national GDP. A comprehensive application of the UNFC contributes to a better understanding of the project, while potentially contributing to the sustainable development of Italy through the implementation of a comprehensive resource recovery management system, the United Nations Resource Management System (UNRMS).

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Acronyms

BGS	British Geological Survey
C.E.T. Srl	Compagnia Europea per il Titanio
CO_2	Carbon Dioxide
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
CRM	Critical Raw Material
CRN	National Center for Research
EC	European Commission
ECI	Economic Importance
EGRM	Expert Group on Resource Management
EIA	Environmental Impact Assessment
ESG	Environment, Social, Governance
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GT	Grade multiplied by Thickness
IPPC	Integrated Pollution Prevention and Control
ISPRA	Geological Survey of Italy
ISR	In-Situ Recovery
NMA	National Mining Association
PRMS	Petroleum Resources Management System
REE	Rare Earth Element
SCI	Sites of Community Importance
SDGs	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SPA	Special Protection Areas
SR	Supply Risk

UNECE	United Nations Economic Commission for Europe
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFC	United Nations Framework Classification for Resources
UNPD	United Nations Procurement Division
UNRMS	United Nations Resource Management System
USGS	United States Geological Survey
WWF	World Wildlife Fund

Introduction

Background

According to recent studies, it took almost 2 million years of human prehistory and history for Earth's population to grow to 1 billion, and another 200 years more to reach 7 billion [1]. Despite being endangered with a global pandemic (Covid-19) at present, the world's population continues to exponentially increase and stands a little short from 8 billion (2022). In line with predictions evaluated by the United Nations Procurement Division (UNPD), slightly over 22% of growth in population is foreseen for 2050 in comparison with today's population [2]. However, on the European scene, population projections are said to decrease by 0.1%/year by 2050 with regards to its current inhabitant's density, amounting to about 0.71 billion [3]. According to a study published by The Lancet, this decrease in population could be the result of further advancement of women's rights, which will render the fertility rate at more rapid rates [4].

With this noteworthy density growth in mind, along with the existing technological advancement, the changes in the lifestyle, the improved living standards, and the progressive outlook within countries, one shall expect the extractive industries to thrive and prosper. In a developed country, studies state that a newly born baby would need around 1.7 million kg of minerals, fuels and metals throughout their life, assuming an average lifespan equal to 80 years [5]. Extractive industries have become a major drive for most countries, especially developing countries because of their potential to enhance economic growth and reduce poverty. Mining and quarrying solid mineral resources is an important sector of the extractive industries. For example, the mining sector, along with its equipment, technology and services, contributes to approximately 15% of Australia's Gross Domestic Product (GDP), and provides 1.1 million jobs, 10% of Australia's total employment [6].

Mineral resources are one of the greatest endowments bestowed upon Earth. They are the source behind an extensive range of product. In today's world, they are as vital as air, land and water to humanity. To put things into perspective, modern technology is fully dependent on mineral resources. The average cellphone contains over 40 different minerals, including gold, silver and platinum [7]. The management of such important commodities requires high supervision and attention in order to ensure an effective use of these resources with respect to finances and time. Resource management helps organizations, whether they are public or private, to have great control over these resources, which leads to an increase in productivity, reduction of costs, and efficiency improvement. The extraction of these minerals is fundamental to a wide range of products, which are crucial in fulfilling our modern day challenges and needs, such as green technology to shift towards low-carbon emissions, renewable energy, and microelectronics. Although all raw materials are vital, some of them are of more concern. Critical Raw Materials (CRM) have high economic interest and are vulnerable to supply disruption [8]. These elements are a dire necessity as they are directly linked to all industries through every supply chain. They are crucial for a technological progress towards a sustainable future due to their liaison with the environment and green technology. Unfortunately, CRMs are still irreplaceable. As a result, the majority of ore deposits have been almost entirely depleted at present times. This issue puts the global mining industry in front of new challenges, meaning that their constant supply of minerals faces more challenging deposits; increased depth, lower ore grades, more safety risk, etc. In addition, nowadays the mining industry, in most countries, is required to abide by new regulations with the purpose of minimizing environmental and social impacts.

Thesis Motivation

Sustainable development is becoming a trend today. This innovative action plan is built on the premise of maintaining a steady economy, achieving a prosperous society, and combatting climate change. Sustainable development allows our modern society to meet its needs, without compromising the opportunities for future generations. In the year 2019, the globe has witnessed the second warmest year to be recorded, as well as the warmest decade (2010-2019) on record. Additionally, carbon dioxide and greenhouse gases have reached records high in the atmosphere, during the same year [9]. Facts and figures regarding these record highs impacting the whole planet stresses on how climate change mitigation is a necessary division for a sustainable development. On the other hand, in terms of mining, sustainable development aims at reducing conventional mining methods into more environmentally and socially accepted ways, as part of its principles. This intention has led governments to promote circular economy, recycling. In fact, several important minerals have great technical potential as well as great economic inputs when recycled. However, due to numerous issues, mainly its incompetence to meet the vast demands of certain elements, the recycling output rates are yet insufficient. As a result, it is safe to say that end-of-life material recycling have a long way to fully replace primary extractive. On that note, the CRM value chain shall remain excluded from the circular economy, for now. For that matter, the idea of sustainable development seeks improved ways to mine sustainably.

As a mean to solidify the seriousness of sustainable development, 193 member states of the United Nations have agreed on an ambitious action plan in 2015, the 2030 Agenda for Sustainable Development, which is targeted at achieving prosperity with respect to planet Earth and its inhabitants. This Agenda's plan is set to be accomplished by 2030 and is broken down into 17 Sustainable Development Goals (SDGs) with the intent of not leaving anyone behind [10]. These targets aim to end poverty, to reach zero hunger, achieve gender equality, provide clean and affordable energy, etc. These SDGs are essential to diminish the threat of climate change, allowing a better, more protected future. The mining industry has the potential of becoming a major influence of Agenda 2030; it has the capability to help achieve the SDGs, as it is directly linked to them. Through their operations, mining companies can decrease poverty by generating employment, profits, and economic growth in developing countries. From another aspect, mines can extend beyond their lifespan to assure a positive impact on the environment and climate through partnerships with governments and local communities [11]. As previously mentioned, mining companies committed to SDGs will have the responsibility of adapting improved, sustainable technologies, reducing wastes, and increasing safety measures, which leads to good relations with local communities, as well as improvements in environmental managements. Furthermore, can contribute to the SDG target "Energy Access and Sustainability" by leveraging their demand for energy in order to spread power to undersupplied areas, via their communal and governmental partnerships, which enables a shared use of energy infrastructure. With that being said, supply of energy, effective production, and mineral resources are vital to accomplishing the 2030 Agenda for Sustainable Development.

In addition, the Paris agreement has strengthened the actions needed to support the plan of a sustainable development in 2015. This internationally treaty emphasizes mainly on climate change, which marks a milestone on this topic, through a legal bind of 196 parties from all over the world. Climate change is directly impacting every country on this globe by disturbing national economies with negative effects on lives. There is no doubt that noticeable weather changes are becoming more extreme, for instance, sea level rise. The urgent measures needed for climate change were covered by the Paris Agreement. This agreement works on the basis of strengthening the global response to climate change threats by maintaining a global temperature rise below 2˚C this century with respect to pre-industrial levels. As an initial step, Governments have started to establish carbon neutrality targets, as a solution to decrease Carbon dioxide (CO_2) emissions. The aforementioned goal shall allow countries to manage the impacts of climate change. Countries will be able to support one another, by implementing suitable financial flows, an enhanced capacity building framework, and improved technologies. The latter puts mining companies in a tough situation, as they are required to multiply productions.

Aims and Objectives

The world is emerging towards a new revolution determined by several trends and technologies. Organizations, governments, and communities are keen to create and adapt modern revolutionary models in energy and resource flows. These models are shaped by the Paris Agreement on climate change and 2030 Agenda for Sustainable development (2030 Agenda). New conventions, strategies, and innovative models are set to reform production and consumption, but more importantly new and unified managing methods for the resulting energy and material flows are a must. These resources are needed to be developed sustainably. As previously mentioned, the sustainable production, transformation, transportation, and consumption of mineral and energy have remarkable impacts on the environment, despite the outstanding improvements over the past decades. However, the sector's stakeholders support further improvement. Therefore, emerged is an essential requirement of having universally accepted standards and guidelines in sustainable resource management to develop and produce a comprehensive assortment of a country's resources. The United Nations Framework Classification for Resources (UNFC) is a widespread, consistent, universal, coherent and efficient resource management system, which is in agreement with the 2030 Agenda and the Paris Agreement. UNFC integrates social and environmental aspects, at its core, together with the criteria of economics, technical feasibility and resource uncertainty. With the mentioned considerations of social and environmental characteristics combined, UNFC has been proven as the only global standard that permits multi-faceted expansion through all energy and raw material resources. Integrating opportunities and challenges is a process that ensures sustainability. Increasing productivity while aiming for 'zero waste,' as well as gaining net environmental and social benefits, are just a few of the many advantages that come with using UNFC. This framework classification system is aimed at those who pursue not only profit, but also fair social and environmental outcomes from resources. Overall, the thesis intends to highlight the importance of UNFC in resource management and its contribution to national economy, while supporting a sustainable and protected future. The aim is achieved through a case study that demonstrates how UNFC can be used on a resource deposit, along with relevant recommendations and discussion.

The United Nations Framework Classification for Resources (UNFC)

Generic Overview

The adaptation of Sustainable Development Goals (SDGs) has amplified the interest of managing raw material and energy resources using sustainable means. Ever since, all forms of stakeholders, from governments and industries to investors and communities, became devoted.

To begin with, the United Nations Framework Classification for Resources (UNFC), developed by the United Nations Economic Commission for Europe (UNECE) and the Expert Group on Resource Management (EGRM), is an internationally recognized and globally applicable resource classification system based on projects and principles. UNFC is a universal tool for consistent, simple classification and competent management of all resources. With that said, it can be applied to minerals, nuclear fuels resources, hydrocarbons, anthropogenic resources, injection projects for underground storage of CO_2, and renewable energy. The latter includes all related sources, such as wind, water, hydrothermal, solar, bioenergy, and hydro-marine. Those mentioned sources are the foundation of each developed product from a resource project. The resources can be assessed in their natural (primary resources such as minerals) or secondary (such as anthropogenic sources, mine tailings) state. Furthermore, this system provides a unique framework capable of building international energy and raw material policies/studies, of supporting governmental resources management laws/regulations, of planning new industrial processes, and of assigning capital proficiently [12]. On this note, UNFC acknowledges the fact that the products of a resource project can be different from the sources, specifically for renewable energy where product can be, for instance, electricity whereas the source can be solar. The stress on the difference is noted because for other projects, the product and source are similar e.g. in hydrocarbon projects where oil/gas are both source and product.

The United Nations Classification System for Resources (UNFC) is defined in function of the sustainable viability (environment, social, and economic), technical feasibility, and maturity of a resource development project. In addition, this classification system allows a steady framework to describe the level of knowledge, the degree of confidence, in the estimates of future quantities available, produced, and/or with recoverability potential by the project. According to Webster's Dictionary, a project is defined as planned piece of work with a specific goal [13], whereas in UNFC a project is considered to be a development or an operation from which the basis of sustainability, technical assessment, and decision-making are provided. The project can be planned in details or remain a concept e.g. a project of long-term national resources plan. However, the project should be planned with details in order to allow a correct evaluation for stakeholder's decisions at a defined degree of maturity. The aforementioned criteria allows the UNFC to reflect on conditions in the environmental, social and economic domain, which includes markets and government framework settings, environmental and social attention, project maturity in terms of technology and industry, as well as the acknowledgement of the inevitable uncertainties that are all in alignment with the requirements of the 2030 Agenda. An additional benefit of this classification system is its adaptability and flexibility for diverse national, regional requirements. As stated by the UN, several countries have taken initiatives for the application of UNFC, such as the European Union, African Union, Russia, China, India, Mexico, etc.[14]

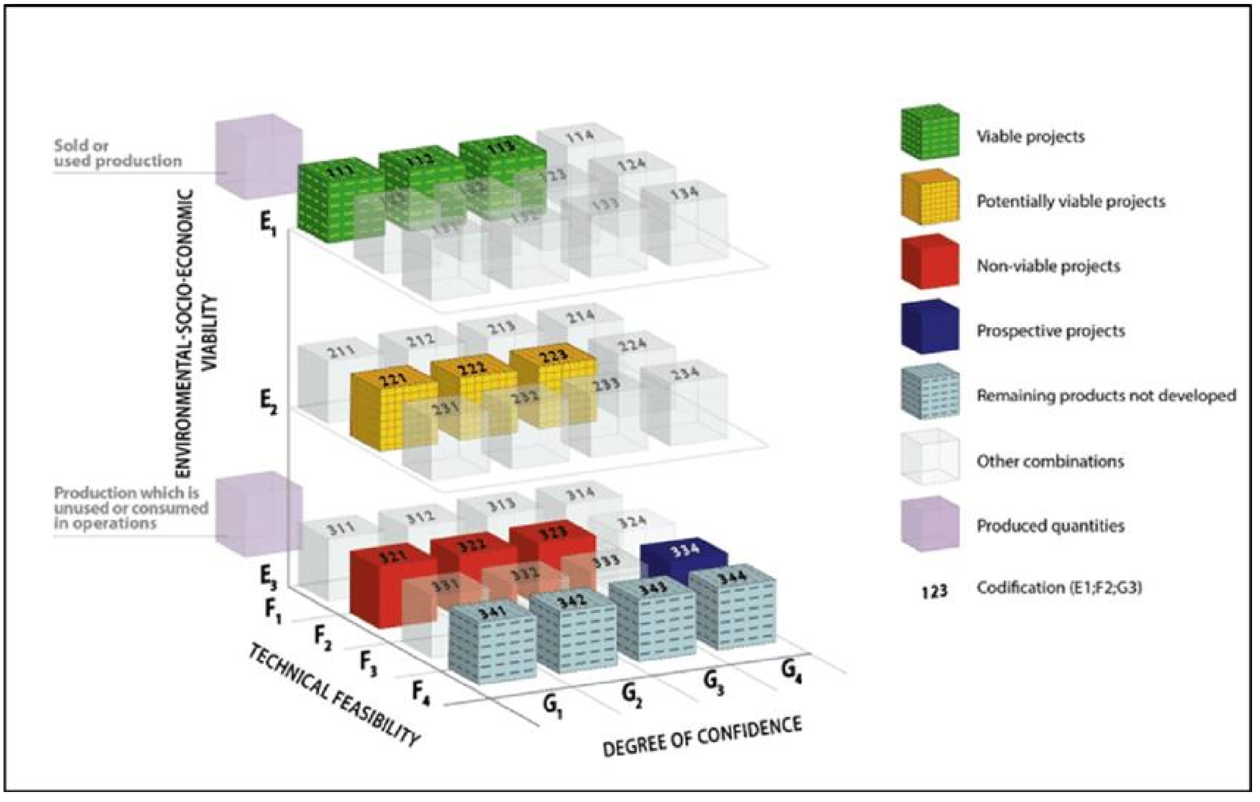
Due to its universality and flexibility, UNFC is recommended to include the full spectrum of the numerous commodities and stakeholders, with the intention of satisfying all requirements for the various resource sectors and implementations while being in complete alignment with the 2030 Agenda of Sustainable Development. For that purpose, UNECE and EGRM have branched different documents of UNFC to make it applicable for all related resources. However, these documents do not modify the core of the generic version, meaning that the initial classification system remains alike. Over the years, UNFC has been updated to keep up with modern policies as well as making its application simpler for users. To date, the most recent version was updated in 2019.

UNFC is a classification system, based on resource projects and principles, which defines the environmental-socio-economic viability as well as the technical considerations of the said projects. This classification system is designed to maximize the needs of applications relating to policy preparation founded on resource studies, resources management functions, corporate business processes, and financial capital allocation. The classification is planned as a 3-dimensional model, incorporating three essential factors in the form of axes, using a simple numerical coding system. The axes are comprised as following:

- Environmental-socio-economic viability (E);
- Technical feasibility (F);
- Degree of confidence in the estimate (G).

The combination of the above criteria can be visualized by this 3-dimensional system (Figure 1). These three factors are defined by categories, and, in some cases, sub-categories. The first axis (E) is designated to the level of favorable conditions regarding sustainability (environmental, social, and economic) in investigating the viability of the project, while considering market prices, legal and regulatory concerns, social and environmental features, and contractual conditions. Secondly, the F axis describes the maturity degree of the project in terms of technological implementation, and the necessary feasibility studies and obligations. This factor integrates a full scope of projects, from preliminary abstract studies through to a fully functional, producing project, which reflects the principles of a standard value chain management. The G axis, third criteria, is appointed to the level of confidence, the degree of knowledge of the estimated quantities of the product from the project.

Figure 1: UNFC Categories and Examples of Classes [12]



The three axes combined, create the Categories and Sub-categories which are the building blocks of the classification system. In return, Categories and Sub-categories are joined in the form of "Classes", represented in a more practical 2-dimensional table (Table 1). The classification of this framework is numerated following one same sequence (i.e. E; F; G) that defines a Class. A side note, since the codes are always repeated with the same sequence, the letters can be dropped, leaving just the numbers (i.e. 1; 1; 2). Each Class has a unique description defined by the selection of the relevant combination of the three criteria of a particular Category or Sub-Category. Although the various combinations of E, F, and G Categories and/or Sub-Category have no explicit constraints, some are more remarkable than the others. These noteworthy combinations, Classes and Sub-classes, have specific labels that serve as a support to the coding system (Table 1). The definitions and explanations of the Categories and Sub-categories are attached in the annex (Annex 1).

Table 1: Abbreviated Version of UNFC, showing Primary Classes [12]

<table>
<tr><td rowspan="12">Total Products</td><td rowspan="2">Produced</td><td colspan="4">Sold or used production</td></tr>
<tr><td colspan="4">Production which is unused or consumed in operations</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Class</td><td colspan="3">Minimum Categories</td></tr>
<tr><td>E</td><td>F</td><td>G</td></tr>
<tr><td>The project's environmental-socio-economic viability and technical feasibility has been confirmed</td><td>Viable Projects</td><td>1</td><td>1</td><td>1, 2, 3</td></tr>
<tr><td rowspan="2">The project's environmental-socio-economic viability and/or technical feasibility has yet to be confirmed</td><td>Potentially Viable Projects</td><td>2</td><td>2</td><td>1, 2, 3</td></tr>
<tr><td>Non-Viable Projects</td><td>3</td><td>2</td><td>1, 2, 3</td></tr>
<tr><td colspan="2">Remaining products not developed from identified projects</td><td>3</td><td>4</td><td>1, 2, 3</td></tr>
<tr><td>There is insufficient information on the source to assess the project's environmental-socio-economic viability and technical feasibility</td><td>Prospective Projects</td><td>3</td><td>3</td><td>4</td></tr>
<tr><td colspan="2">Remaining products not developed from prospective projects</td><td>3</td><td>4</td><td>4</td></tr>
</table>

The table above illustrates that the total product, ready for development or under production, is classified within a given timeframe. This means that project lifetime and/or limit require essential concern for the quantification of the product i.e. projects for renewable energy.

Given the considerations, the classification happens in terms of the following:

- Quantities produced that have been sold or consumed i.e. direct domestic use of a solar home installation or non-sales domestic supply of a product to a local market.
- Quantities produced that have been consumed in operations or unused.

- Quantities of a known product that may be useful in the future. The classification is based on technical and environmental-socioeconomic evaluation studies based on projects.
- Quantities produced which remain undeveloped by any project.
- Quantities of a product that could be generated in the future as a result of prospective projects. The classification is based on technical and environmental-socio-economic evaluation studies based on prospective projects.
- Quantities produced which remain undeveloped by any prospective project [12].

The total products described are conserved by a complete application of the classification for all projects at the source. An important term "reference point" is introduced for this purpose, which establishes the situation of product quantity, quality, sales, transfer, and price as determined. Yet, this does not apply to former measured productions of the product, where quantities are always estimated. Therefore, a margin of uncertainty associates these estimates. This uncertainty is thus communicated throughout the assessment, either by citing distinct quantities with reducing degrees of confidence (high, moderate, and low) or by analyzing three sets of specific scenarios with best, high, or low estimated outcomes. The latter (low) scenario, is directly associated with estimates of high degrees of confidence (i.e. G1). On the other hand, the best estimate scenario corresponds to a combination of high and moderate confidence estimates (i.e. G1 + G2). The last scenario (high) is equivalent to a combination of all levels of confidence (high, moderate, low) estimates (i.e. G1 + G2 + G3). The estimation of the quantities can be determined using deterministic or probabilistic approaches. Projects that are different from "Viable Projects" depend on one or several other conditions in need to be fulfilled. These "dependent projects" are thus further divided into projects with environmental-socio-economic conditions that are projected to be adequate for development, and those that are improbable.

Since UNFC is global, further universal communications are introduced as additional Sub-Classes based on the total granularity of the definitions by the Sub-categories (Annex 1). Table 2 projects the former. Other classifications, than the ones in Table 1, can be combined by selecting the appropriate groupings of Categories, or by combining/further dividing the Categories (Table 2). The harmonization of developed national inventories is permitted on the basis of different systems. In opposition, when UNFC is adapted for the building of an inventory, the conversion from/to inventories developed by other harmonized classifications can occur without the need to restart from basic information. For this purpose, UNFC is designed in a way that aligns it with some former classification systems. Therefore, bridging documents are presented to explain the relationship between UNFC and other classification systems, with instructions that clarify the classification of estimates generated by the application of the other system using the UNFC Numerical Codes. Bridging documents allow the adaptation of UNFC to resources that were already classified using other systems. These documents “bridge” UNFC to the Committee for Mineral Reserves International Reporting Standards (CRIRSCO), Petroleum Resources Management System (PRMS), Oil and Gas Reserve and Resources Classification of the Russian Federation of 2013, etc.

The flexibility of UNFC permits the classification to be adapted to national, local needs. However, changes of this sort should be double-checked for steadiness in line with UNFC and other used applications. Furthermore, these modifications from UNFC should be documented when implied, for transparency purposes. For governments, the estimates of national products can be based on the accumulation of documented or reported estimates from corporates for each project. Though, these estimates might not include all active or potential developments. In addition, when governmental organizations are tasked to develop regional or national estimates, the process may differ from estimates reported from corporates for individual projects, with no regards to which classification system is being adapted. For cases of such, the nature and availability of certain data are of high necessity in order to implement an appropriate methodology for the development of UNFC for estimates at national or regional levels, of course by disclosing the aggregation methods. The specifications for UNFC mandate the disclosure of relevant Numerical Codes for each Class when implementing aggregated estimates. To elaborate further, at a national level, determining the total sum of the estimated quantities may be useful for Viable Projects and/or Potentially Viable Projects with a Best estimate degree, but further sub-classification of Classes is preferred to be also provided. The classification of a project using UNFC includes the environmental and social matters concerning the 2030 Agenda for Sustainable Development Goals (SDGs), matters that can affect project development. To elaborate more, the E-axis Categories are unambiguously devoted to both social and environmental factors, which have the power to define the viability of the project, when classifying it. In addition to these factors, the economic, legal, and other non-technical aspects are considered. At a certain point in time, the consideration and identification of the estimates of these sustainability factors, that can influence the project at any time during its life cycle, are reported as an important portion of the assessment. The occurrence of environmental and social issues can seriously damage a producing project, by preventing it to proceed or leading to a temporal suspension or full termination of its activities. On the other hand, the availability of positive environmental and/or social externalities can be an essential driver for a project to start. In this case, the project classification will report the maturity levels of the social and environmental factors, as well as their impact of the project development.

Table 2: UNFC Classes and Sub-classes defined by Sub-categories [12]

UNFC Classes Defined by Categories and Sub-categories						
Total Products	Produced	Sold or used production				
		Production which is unused or consumed in operations				
		Class	Sub-class	Categories		
				E	F	G
	Known Sources	Viable Projects	On Production	1	1.1	1, 2, 3
			Approved for Development	1	1.2	1, 2, 3
			Justified for Development	1	1.3	1, 2, 3
		Potentially Viable Projects	Development Pending	2	2.1	1, 2, 3
			Development On Hold	2	2.2	1, 2, 3
		Non-Viable Projects	Development Unclarified	3.2	2.2	1, 2, 3
			Development Not Viable	3.3	2.3	1, 2, 3
		Remaining products not developed from identified projects		3.3	4	1, 2, 3
	Potential Sources	Prospective Projects	[No sub-classes defined]	3.2	3	4
		Remaining products not developed from prospective projects		3.3	4	4

Guidelines on the Application of Project Maturity to Classify Projects Using UNFC

The guideline elaborates on the use of project maturity to classify and sub-classify projects using UNFC. It provides a range to subdivide projects, using the wide scope of Sub-category definitions (Annex 1). The use of the system at this degree of coarseness is optional, though it is highly recommended at corporate and national levels, as it enhances the tool for precise management. Further classification reflects the notion of classification based on project maturity, which largely relates to the possibility of a project to achieve a viable operation. To assign an apt Sub-Class to a project, the consideration of all specifications relating to advanced classification levels, as well as Categories and Sub-categories definitions shall be evaluated. Sub-Classes related to project maturity correspond to the relevant actions that are necessary to uplift a project towards viable developments (i.e. corporate decisions, legal permits, etc.). The borders in-between the levels of project maturity are in liaison with internal business project decision-making. Therefore, this directly bridges decision-making, company's capital value, and the arrangement of project scope of assets through resource classification.

Project developers always seek to move upwards in Classes, towards higher levels of project maturity, to reach viable productions. However, it is noteworthy to mention that undesirable circumstances, such as changes in market prices or local social considerations, can cost the project maturity to downgrade towards lower Sub-Classes. As projected in Table 2, if a Sub-Class is adopted, guidelines should be implemented as the following:

(a) Viable Projects:

<u>On Production:</u> Applied when project is in production, as in selling and/or using the products as of the issued date of the assessment. Even if the project might not be fully complete at that given day, the completion of the project shall possess all required approvals and permits in place, as well as capital funds engaged. In the case where a section of the project development plan is under an ongoing, uncertain process for a separate contract, permit and/or assurance of capital funds, this section should be separately classified with a proper Sub-class.

<u>Approved for Development:</u> This Sub-Class is applied when the necessary permits and/or contracts are available, as well as the commitment of capital funds. In terms of project development, the required structures and facilities for the project production should be underway or awaiting to be launched shortly. The project should be foreseen with high certainty for development unless an unsought alteration in conditions, which is beyond fixable by project developers, can result in failure of the project to proceed in development within a relevant time period.

Justified for Development: Applied when all the required approval, permits are expected to be forthcoming, meaning that technical feasibility and sustainable viability of the project have been demonstrated, approved.

(b) Potentially Viable Projects:

Development Pending: This Sub-Class is restricted to projects that are actively subjected to technical issues specific to the project (e.g. appraisal drilling is pending for additional data acquisition) and/or project feasibility studies are to be completed yet along with the associated social- environmental- economic assessments related to the confirmation of project viability and/or to design the most favorable development set-up. Additionally, it includes projects that are subjected to nontechnical incidents, under the condition that they are currently being consistently pursued by project developers and expecting to be resolved accordingly within a reasonable period of time. These projects are highly probable of achieving viability.

Development On Hold: Applied when a project is considered to have reasonable potential of achieving viability (e.g. economic production are foreseen from prospection), though it is currently subjected to serious non-technical contingencies (e.g. waiting to solve major environmental issues). These contingencies are required to be solved prior to resuming project progress, initiating development.

The main difference between the above-mentioned Sub-Classes is that the case of Development Pending is restricted to issues that can be solved, handled by project developers (e.g. via negotiations) whereas in the case of Development On Hold, the primary contingencies are beyond the decisions of project developers, meaning that they have little to no direct impact on the outcome and the timing of decisions related to significant uncertainty.

(c) Non-Viable Projects

Development Unclarified: Appropriate Sub-Class for projects that are still in the preliminary stages of development i.e. environmental-social-economic and technical analysis still under study, for instance newly discovered deposit. Significant additional data acquisition is required at these stages, which will allow the pursuit of reliable evaluation for a potentially viable development, meaning that the available information is insufficient to concur whether there are rational projections for an eventual viable project.

Development not Viable: This Sub-Class is applied when projects technically feasible are assessed, but have been proven to be with insufficient potential to authorize any further data acquisition or any direct actions to eliminate the contingencies. For such scenarios, it is helpful to recognize and document the available quantities in the case where significant variations of these contingencies move the project towards potentially viable development opportunities.

(d) Remaining products not developed from projects

Remaining products not developed from projects is selected for the classification of the quantities in which their identified projects are rendered to being non-technically feasible for the opportunity of producing of any of these quantities. New, enhanced technology may lead to the subsequent production of these quantities in the future.

The Purpose of UNFC

Many case studies on the application of UNFC to a variety of resources have resulted in several benefits and opportunities. For instance, Jolović have noted the following advantages of UNFC from the experience of its application to groundwater resources and energy in Bosnia and Herzegovina [15]:

- Easily applicable to a large scope of commodities (e.g. minerals, petroleum, renewable energies, water, etc.)
- Aptly designed for national and/or regional reporting scopes while accommodating different types of information.
- A simple, robust, sustainable tool that is capable to incorporate all aspects within the resource management context, providing a reasonably thorough portrait of resource stocks.
- Adaptable to all kinds of projects, including prospects, undeveloped resources, and historical estimates.
- Globally recognized.

A common challenge UNFC users face is to understand how projects and resource stocks are classified, how the data is presented, and how results are interpreted [16]. However, the misconceptions are well addressed in UNFC2019 and all related documents. Furthermore, UNFC users are compiled from many different sectors, from all around the world. New users can benefit from the development of an open access system, which makes their experience with UNFC much simpler. In addition, official authorities and governmental establishments can mandate such tool amongst their national framework in order to familiarize users with UNFC, thus; making it easier. For most projects, developers often seek investors. UNFC can facilitate the leap that banks and other investors take before financing a project [15]. For example, if the classification of a resource project using UNFC shows to be viable or potentially viable, mining companies or other organizations of the energy sector will express great interest in purchasing such resource related projects, as UNFC renders the project data simple and understandable for decision-makers. For that purpose, the use of the UNFC as a reporting tool is highly recommended to all forms of investors, regulators, stock exchange and Environment, Social, Governance (ESG) reporting standards. Some see the implementation of UNFC as an opportunity for oil and gas companies as the current situation is drifting away towards more valuable renewable energy-related projects. UNFC can be used in that case to assess project maturity that are being financed and documented to their portfolios to ensure an upcoming pipeline of projects [16].

It has been established in previous paragraphs, that UNFC facilitates the decision-making task to stakeholders. In fact, there are different ways stakeholders make use of UNFC, depending on the organization (Table 3). The most integral aspect of decision-making is having sufficient, credible information on a resource and/or a related project [17]. Within the same context, reliable information is crucial at national and/or regional levels, as governments are expected to ensure transparency while maintaining trust to stakeholders, including the public and potential investors. UNFC can also help governments and the public in understanding the resource potentiality their realm holds, by documenting and reporting the necessary data. In this case, all forms of stakeholders become aware of projects with potential in the future as well as the projects pipelines that are undergoing development. To support this idea, albeit the fact that UNFC is project based, it also allows data to be integrated into the aforementioned UNFC Classes, making it the tool for investors and stakeholders to have a vivid picture of the potential and under development resources in long terms activities as well as short-terms to correctly handle commodities. Additionally, due to its flexibility over the various resources, its use makes it possible to compare them within national and regional boundaries i.e. a country’s decision to shift to renewable energy in contrast to continuously depending on hydrocarbons.

Table 3: Potential uses of the UNFC by Stakeholders [15]

Type of organisation	Potential uses of UNFC
Project developer	Monitor project progress on each project they are developing, report progress to government agencies, report portfolio of projects to investors
Equity investor	Assess the viability of a project they are considering investing in Assess the portfolio of projects held by an enterprise they are considering investing in Monitor a portfolio of projects
Banks	Assess the viability of project wanting a loan Assess the viability of enterprises with portfolios of projects wanting loans
Utilities	Assess the viability of a project they are considering buying Assess the portfolio of projects held by an enterprise they are considering buying Monitor their portfolio of projects
Stock exchanges, financial and ESG regulators*	Ensure that information reported by enterprises is done using appropriate standards and is trustworthy, including natural resources related information and ESG related metrics
Government agencies and research organisations	Assess the project pipeline for the country and different areas in the country
Communities and other stakeholders	Assess projects and resources that might be developed including alternatives

UNFC for Minerals and Italy

Case Study Incentive

The case study implemented in this thesis is aimed at providing considerations associated with the application of UNFC, with a particular emphasis on specific guidelines for its application to a Titanium resource project in Liguria, Italy.

It is an accepted fact that minerals allow humanity to sustain its standards; minerals make life. The mining industry accounts for a significant share in the economy of various countries. By creating job opportunities as well as producing the important minerals to the majority of active sectors, the mining industry stimulates economic growth. In 2020, the National Mining Association (NMA) has reported $700 billion, about 3% of the United States' GDP, from mining activities [18]. In contrast, the mining and quarrying sector in Italy has contributed $2.7 billion to the economy in 2020, less than 1% of Italian GDP [19]. The contribution of the mining industry to the economy in Italy is considerably low in comparison to other EU countries, such as Sweden and Germany, and is amongst the fewest in the world. In fact, the Italian GDP is mainly supported by the manufacturing and services industries.

On the other hand, the mining industry is expected to gain great importance to meet today's collective goals, especially from the result of variations in the market conditions sustained by robust encouragement from governments. Despite the drawbacks in mineral production over the last decade, mining and quarrying remain of strategic importance for the Italian economy. In fact, experts forecast an improvement in market conditions because the extractive industry, specifically mining, shall offer several opportunities for investment as most of Italy's commodities are yet still substantially underexploited. Various ceased mines are expected to return to operation in the near future per say. For example, the Gorno mine in Lombardy, which produces metallic minerals (Lead, Silver, Zinc), is scheduled to reopen for business in 2021-2022, since its last shutdown in 1980 [20].

At the present time, Italy remains one of the leading producers of the world for certain industrial minerals, such as feldspar. According to the United States Geological Survey (USGS), there are 106 mining concessions in Italy, with only 54 operating mines mainly extracting industrial minerals (e.g. cement, marls, feldspar), and some metalliferous minerals (e.g. zinc, lead, copper) (Figure 2 & Table 4) [21]. Italy's complex geology and diverse lithology have permitted these mines to be mainly concentrated in Northern Italy (i.e. south of the Alpine arc), central part of Italy, and Sardinia.

Figure 2: Current active mines in Italy [22]

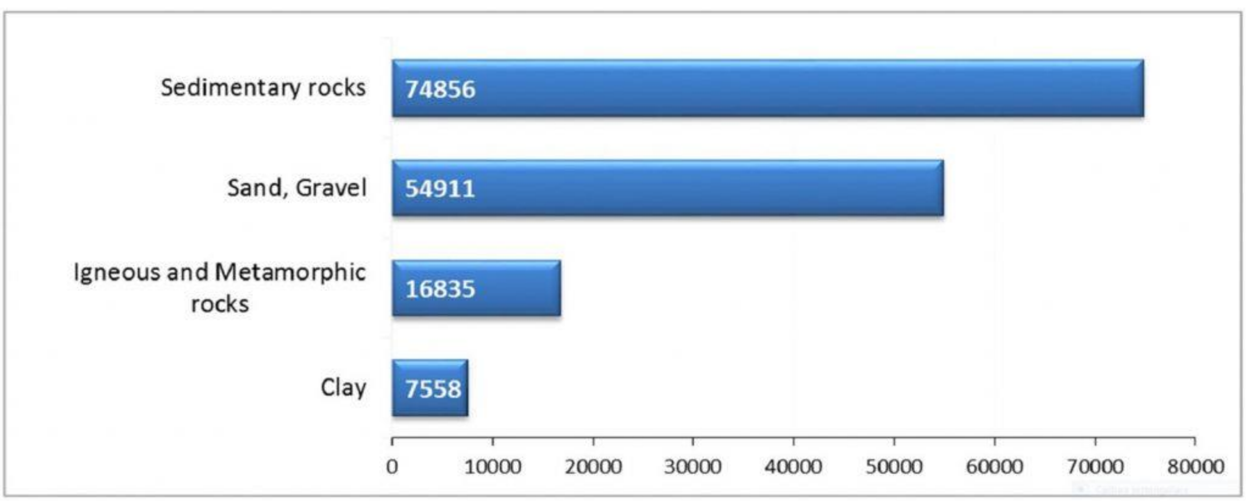
Table 4: Mineral productions (tons) in Italy between 2015 and 2017 [21]

	2015	**2016**	**2017**
Cement marls	5185	5537	5980
Industrial minerals (Kaolin, Feldspar, Bentonite, Clays)	5223	5703	6186
Salt	2081	2085	2147
Others (Talc, Baryte, Fluorite, Olivine, Magnesium salts)	1490	345	510
Total Production (t*1000)	**13980**	**13671**	**14823**

The extractive industry in Italy is surely carried by the quarrying activities as Italy is home to some of the world's most famous dimension stones. The Carrara and Massa quarries found in Tuscany have the reputation of producing exceptional white marble. According to the Geological Survey of Italy (ISPRA), 2630 quarries were operating by the beginning of 2018 in various regions in Italy (Figure 3) [23]. Productions from these quarries include aggregates consisting of sand and gravel (67% of active quarries) and ornamental stones. Aggregates quarries are widely spread amongst the Italian territory around valleys and plains. Italian dimension stones consist of a wide range of rocks, igneous (granite mostly produced in Sardinia), metamorphic (Tuscany marbles), and sedimentary (limestone, marls, and chalk mainly in central Apennines) (Table 5).

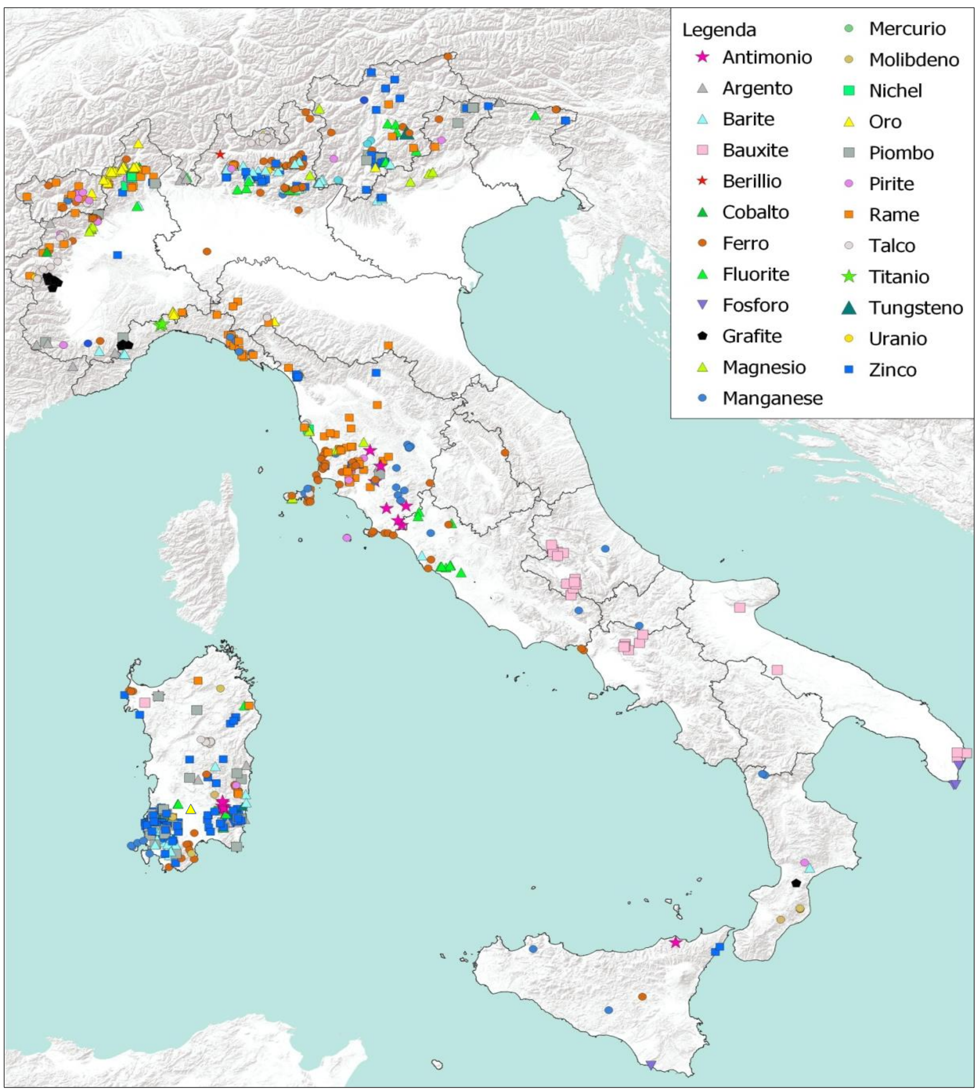
Figure 3: Current active quarries in Italy [23]

Table 5: Quarrying production in 2017 (tons) [23]



The mining history of Italy demonstrates how diverse Italian lands are in mineral deposits, which include many metallic ores, Rare Earth Elements (REE), and CRMs. These deposits are unequally scattered over Italian territory. In line with the unique geology of the Alps, the Alpine arc in the Northern region of Italy is rich in a wide range of minerals, such as cobalt, gold, lead, and even uranium. The central west coast of the country displays high concentrations iron, aluminum, and manganese. In addition, the island of Sardinia shows an immense variety of deposits with economic concentrates, including REEs, gold, zinc, barite, etc. Furthermore, in the South-eastern region of Sardinia, prospect projects indicated 2.5 million tons of exploitable fluorite (Figure 4).

Figure 4: Mineral deposits in Italy [24]



Italy has so much to offer in terms of mineral resources. Most prosperous resource deposits available in Italy today lack technological advancement and modern mining methods of research and exploration. Italy is one of the few countries in the world that is not studying and exploiting its mineral resources and does not have a national strategic supply plan. These contingencies shall allow the reopening of various mines and exploration of deposits that were thought impossible. With the given context of mineral abundancy, the 2030 Agenda, as well as the plan to pursue the European Green Deal, Italy has commenced taking its mineral industry to another level by reopening mines, increasing exploration, and enhancing resource management.

Studies conducted by various universities and by the National Center for Research (CNR) show how it is already possible to revalue, in relation to CRM, fields considered exhausted. For example, in the iron deposits of the island of Elba (hematite, magnetite, and limonite) there are 5-8 kg / t of tin and tungsten, in addition to notable kg/t of cobalt contained in the local pyrite and skarn [24]. Similar situations are present in marginal areas, yet to be exploited, with deposits considered depleted in various regions of south-western and eastern Sardinia (e.g. tin, tungsten, indium, nickel and cobalt in the Sulcis-Iglesiente and Fluminese areas -Arburèse; fluorite, barite, titanium and Rare Earths Elements in the Sàrrabus-Gerrei and in the Sarcidano-Barbagia). Even in the less regarded areas such as Calabria, they have much higher mining potential than formerly believed. Potential and underexplored mineral resources are represented by the volcanoes and submarine reliefs of the southern Tyrrhenian Sea; however, they must be investigated very carefully with regard to the possible environmental effects caused by any underwater activity [24]. This is the case for various other mineral resources, mineralized bodies in Italy that are reported as exhausted (e.g. Gorno) but with prosperous research, modern technology, and the current price trends these bodies appear much more extensive and convenient. For this purpose, a large amount of dormant mines is expected to reopen soon.

Within the context of enhancing the mining sector in Italy, ISPRA has started building a geodatabase "GeMMA" that amasses all relevant information on extractives in Italy such as mining activities, resources and reserves, and mine wastes. The aim of this database is to improve sustainable management and gain a better understanding of Italian mineral resources from active/idle and public/private mines and quarries. GeMMA is developed to include national policies in regards to sustainable mining and quarrying of primary mineral resources, with a circular economy perspective and attention to anthropogenic resources. The GeMMA geodatabase is based on the Minerals4EU Project to enhance national and regional resource management [25].

In agreement with the directive issued by the EU Commission on extractive wastes, Italy has implemented a waste management plan for mining and quarrying projects. In particular, attention is also given to wastes produced in the past and stored in closed/abandoned waste facilities. This plan includes the development of an inventory that collects information from extractive wastes facilities, which facilitates the detection of interesting minerals, such as CRMs, with their quantities and concentrations present in these wastes. The recovery from such process paves the way to a circular economy.

With what was aforementioned, Italy's solid minerals sector will doubtlessly contribute to the national economy in the upcoming years. For this matter, this Thesis includes a case study with the aim of rethinking and strengthening the approach of resource management in Italy. This case study dives specifically into how integrated Titanium and associated metals deposits of the Piampaludo site could improve the development of the Italian solid mining industry. A comprehensive application of the UNFC and an extraction approach shall contribute to a better understanding of the said project, and potentially play a role in the sustainable development of Italy.

Critical Raw Materials (CRMs)

Titanium has always been perceived as an element with great interest. Its remarkable physical and chemical properties serve a great deal in today's society. This lustrous, durable metal is in high demand in various domains, including the industrial, medical, and jewelry sectors. Titanium has been identified as a CRM by the EC as of 2020.

With the inevitable continuous growth in the global population and economy, raw materials are in demand more than ever; though, these materials are subjected to fast rates of depletion from Earth's crust. As a consequence, the issue of future raw material supply is raising major concerns. On the same note, material supply is vastly influenced by social, political, and economic factors; which in return affect market volatility: ergo market prices. As a result, national and regional economies that are significantly dependent on imports of raw material due to shortages in their production, such as the EU, face a serious challenge in ensuring an independent flow for some materials of greater interest; CRMs [26]. As a form of solidifying the European economy, the EC have implemented an initiative to tackle the problem of raw material supply to the region. This initiative is created to assure adequate, sustainable imports from the global market, to interlock a sustainable flow of raw materials within the region, and to build a circular economy through the encouragement of secondary resources supply. Therefore, the EC launches a list of critical raw materials with thorough assessment, every 3 years (Figure 5) [27].

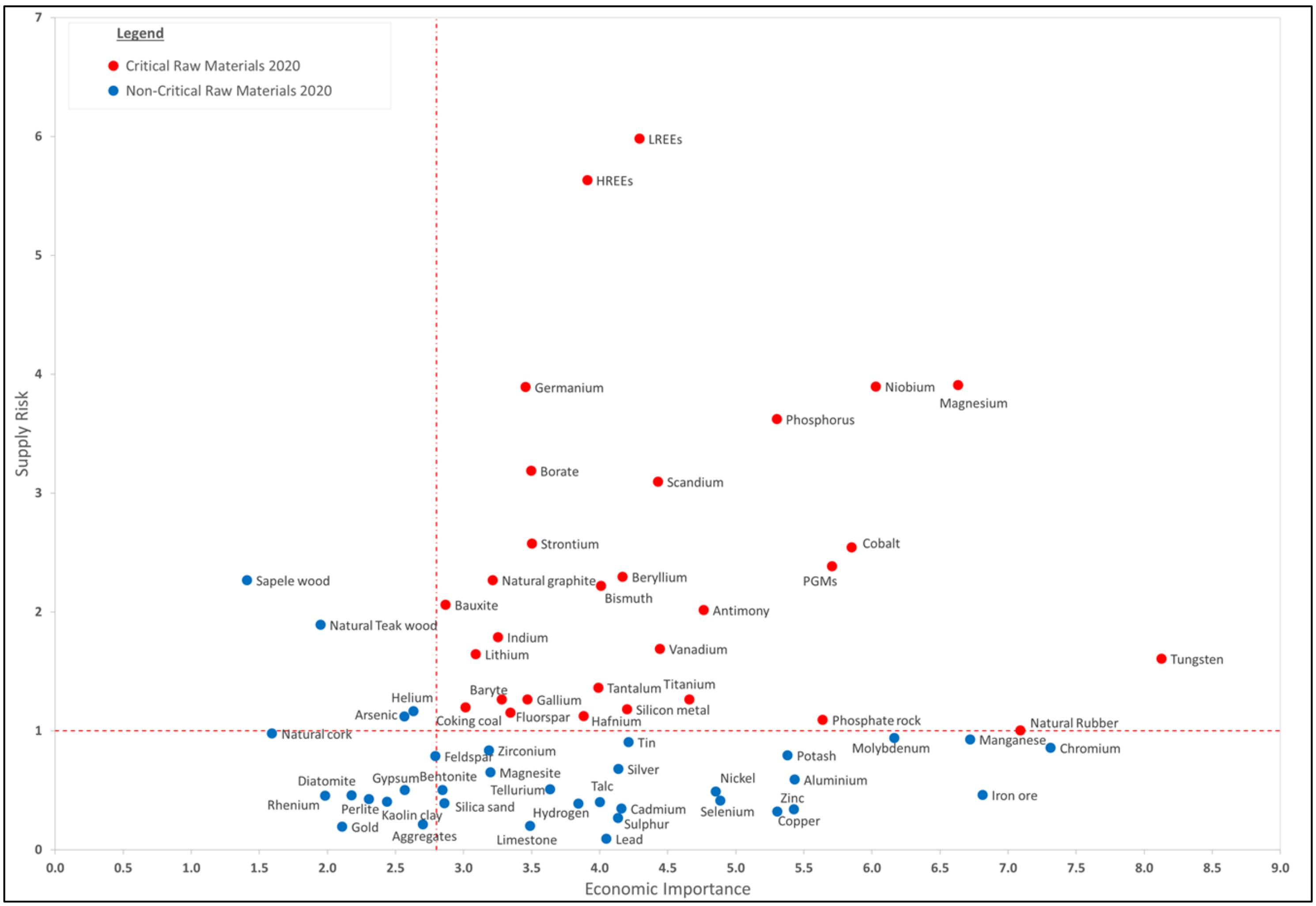
CRMs, also known as Strategic Elements, are raw materials that show great economic and strategic importance for the European economy, yet reveal great risks on their supply. These materials serve many industries, including medical, sustainable technologies, electronics, batteries, etc. but most importantly they serve a crucial role in the sustainable development of the European economy [28]. It is essential to note that CRMs are not identified as "*critical*" because they are considered as "*scarce*". The title "*critical*" is applied for those raw materials because of their high-supply risk, their economic significance for vital sectors in the economy of Europe, and the absence of substitutes. The latter is caused by the distinctive and dependable properties displayed by CRMs for present and future applications. CRMs are classified in function of two parameters, the economic importance (ECI) and the supply risk (SR). On one hand, ECI portrays the material's relevance at the end-of-use application, as well as the value-added by manufacturing sectors with regards to the European economy. On the other hand, SR is evaluated by the risk of material supply interruption to the EU. This factor depends on the quantity of direct supply of raw materials from producing countries. In order to be more conservative, SR for each of the listed material is analyzed according to the most severe scenarios, mainly at the extraction and the processing stages. Moreover, SR is subjected to a reduction in terms of risk, in the case of the possibility for recycling and/or availability of substitutes. Thus, the EC projects the list of CRMs with the consideration of materials assessment in function of their ECI and SR with respect to the defined thresholds.

The attention given by the EU to the listed CRMs rises from their importance; CRMs are vital to Europe. They are key for most mega-sectors in the EU, as well as for a variety of governmental branches and commercial applications, as they are involved in all supply chain phases:

- Green Technology
- Space Exploration
- Telecommunication
- Aerial Imaging
- Medical Technology
- Micro-Electronics
- Transportation
- Defense

These sectors render the access and application of CRMs as major factors for EU's industries, environment, and quality of life.

Figure 5: List of Critical Raw Materials, 2020 [29]



For the purpose of this Thesis, it is important to note that Titanium has been listed as a Critical Raw Material as of 2020, surpassing both ECI and SR thresholds. For comparison, this element was listed as non-critical by the EC in 2017, as Titanium supply showed no supply risk.

UNFC Specifications for Minerals and Mining Projects

As mentioned earlier, UNFC is principles-based tool which facilitates the classification of resources from projects applying a numerical coding method, evaluated on the basis of three essential parameters: "E axis" representing the environmental-socio-economic viability, "F axis" reflecting project's technical feasibility, and "G axis" for the degree of confidence [30]. A key advantage of UNFC is its application to a wide range of resources. With that in mind, each resource was assigned a set of specifications as a mean to further delineate the classification according to the type of resource. Therefore, UNFC for minerals is applied to mineral projects varying from ores to aggregates and coal, with respect to the SDGs [30]. UNFC specifications for mineral projects intend to highlight the classification system within the framework of sustainability, latest technologies and modern management tools.

The minerals specifications clarify the use of certain terms within the context of the mineral industry, in order to correctly apply and justify the corresponding Category and/or Sub-category for a mineral project. According to UNFC specifications for minerals, a mineral source is defined as a deposit with potential economic recovery accumulation of one or several minerals. A mineral project's product may be sold or used, such as mined ores, co-products, by-products, beneficiated ores, and processed ore concentrates [30]. The classification is constricted within a defined mining project, which aims at producing mineral sources to provide an evaluation for the environmental-socio-economic aspect, leading to decision-making. On the other hand, a mineral project aims at providing estimates for the evaluation of the environmental-socio-economic feasibility. The mineral project includes all operations taking place during the mineral life cycle i.e. starting from exploration and prospecting then mining and production, to beneficiation and processing, up until site remediation. The classification can be implemented to any mineral project, whether it's planned with details or still a concept. The feasibility studies to be considered comprise of degree of magnitude, scoping, the preliminary investigations, and level of details. Certainly, the stakeholders prefer having sufficient data for proper assessment of the projects. Another key factor for the specificity of mineral project classification is its life cycle. The mineral life cycle informs stakeholders on the current stage of the mineral's life and the added-values of the project. Products from mineral projects portray the initial entrance of materials into the stocks present for the economic value chains. However, mining products and their compositions are prone to alterations in their process along their length of stay in the added-value chains. The classification requires the definition of a position in a mineral project where estimates have been reported, known as the mineral reference point. This reference point can refer to sales, use, or transfer point from the project [30].

It is important to emphasis on the choice of the adopted mining methods, because they have significant variations on quantity estimation. Mining methods are numerous, subsequently divided into conventional (e.g. Open pit Mining, Room & Pillar) and unconventional (Seafloor Mining, Agro-mining) methods. Each method displays a set of advantages as well as disadvantages, depending on site-specific parameters (e.g. rock mechanics, geology). In general, open pit mining is selected when a homogenous, low-medium grade, fair tonnage deposit exhibits economic feasibility with respect to depth and stripping ratio. On the other hand, underground mining is most commonly opted for a high grade, low tonnage deposit. The main factors outlining the quantity estimates for both approaches vary considerably as the overburden or strip ratio is critical for an open-pit operation by narrowing it cost-effective only to shallow deposits, whereas overburden thickness in underground operations is not considered, but requires an accurate understanding of the ore body at significantly higher unit costs. Potential extraction of co-products or by-products definitely makes primary production more economically feasible and cuts wastes from surface and subsurface mining.

Glossary of Terms for greater understanding of UNFC specifications for mining projects is attached in annex 2.

UNFC Specifications for In-Situ Recovery Mineral Projects

Deposit that are considered to be uneconomical by means of conventional mining may show economic viability if suitable for unconventional methods, such as In-Situ Recovery (ISR). In ISR, the quantities estimate combines supplementary physical and chemical considerations that are irrelevant to surface and subsurface mining. In effect, these considerations are primarily dedicated to the following parameters of the unit:

- Permeability
- Hydrologic confinement
- Solubility of the minerals by weak alkaline or acidic solutions
- Ability to return groundwater within the mined area to its original baseline quality.

Commonly, quantities estimated in ISR projects apply the contour method: grade x thickness (GT). In such case, the minimum GT cut-off is reported. The GT cut-off for ISR projects is determined with a similar method to how grade cut-offs are obtained for conventional mining methods. In addition, quantity, quality and the anticipated recovery of the mineral sources should be documented in ISR projects, as well as the production methods. In fact, this is achieved by reporting the deposit area (e.g. the average thickness and the average GT) or the tonnage (e.g. the average grade and the average GT). The recovery of mineral sources can be reported as a percentage (of the estimated contained mineral) or as the quantity of the recoverable minerals. To state the obvious, the evaluation of ISR methods must account for environmental impacts, as well as means to mitigate or evade harmful consequences of any kind.

Minerals Project Evaluation

A mineral project is assessed following the fundamentals stated in the generic UNFC, but with specifications to minerals, rendering it apt for these types of projects. Numerous methodologies are implemented by mineral projects in several periods of their lifecycle, primarily during quantity estimates of the appropriate project wherein any source of the estimates is properly referenced in the assessment. The classification process for mineral projects is also in function of the environmental-socio-economic viability (E axis), technical feasibility (F axis), and the degree of confidence in estimates (G axis).

The factors determining the environmental-socio-economic viability reflect the balance between mineral projects and the SDGs. Mineral products constitute the building blocks of various SDGs, which raises the attention of understanding the impacts during the evaluation of minerals projects on SDGs, as they are integral to societal development, mostly with regards to the environmental, work safety policies and geo-ethics to sustainably operate a mineral project. The E axis incorporates all non-technical factors that directly affect the development of the project, including relevant market prices and conditions, expenses, legal and fiscal framework, the environment, and all constraints from workers and the local community. It must be noted that each aspect (environmental, social, and economic) is evaluated separately. For future estimated products from a mineral project, in addition to the economic aspect, the E axis also defines the social and environmental issues with regards to the commercial feasibility of such project. Moreover, the time of these impacts is essential for the project assessment and must be carefully considered along the entire lifecycle.

The technical feasibility of a mineral project is defined by the level of maturity of studies and engagements that are necessary for project development. The relevant studies and commitments extend from the early exploration/prospect stage to a producing/selling project. The F axis encompasses all technical factors that have direct effect on the viability of minerals projects to develop. These factors include the mining method opted, rock mechanics, volumes, waste disposal management, technology, and processing method adopted.

The estimate of product quantity is related to the degree of confidence in the estimate. For minerals projects, the G axis reflects the level of geological knowledge with regards to quality and quantity of the mineral product.

Titanium as a Resource

Prior to the release of the latest list of CRMs by the EC in 2020, titanium was thought as an abundant element, with no risk of supply. However, at present times, this element entailed great concerns in terms of increased supply risk as its economic importance ascends. Titanium has been a key commodity for several industries within the past century [31]. This element is listed as a CRM because of its characteristic properties, which eliminates the possibility of substitutes, to the possible extend, with full satisfaction. This heavy metal possesses a unique lustrous, metallic silver tone and is mostly characterized by its excellent weight-to-strength ratio, resistance to corrosion, and its extremely high melting point [31]. Titanium substitutes, such as lithopone, usually result in low quality products with less environmental caution.

In most common cases, titanium naturally occurs in minerals that consist of titanium-bearing oxides (e.g. as TiO_2), which are mined from natural resources and/or synthetic process of these minerals. Commonly found titanium-bearing minerals encompass Ilmenite, Rutile, and Leucoxene. Ilmenite ($FeTiO_3$) occurs as a magmatic mineral and is the main ore of titanium (e.g.

accounts for about 93% of the world's titanium resources), whereas the remaining concentrates mainly occur in the metamorphic form as rutile (TiO_2). On the other hand, Leucoxene occurs from the weathering of ilmenite, forming fine crystalline aggregates of rutile and anatase, with titanium dioxide concentrations greater than 70% [31]. Other titanium-bearing minerals include hemo-ilmenite (ilmenite with extensive hematite, Fe_2O_3), and titaniferous magnetite (magnetite with Fe-Ti-Oxide, Fe_3O_4) that occur generally in high concentrations but with low Ti-concentrates i.e. low economic viability. The remaining titanium concentrates are often found as sedimentary deposits, amassed from the erosion and weathering of source rocks with ilmenite and rutile concentrations.

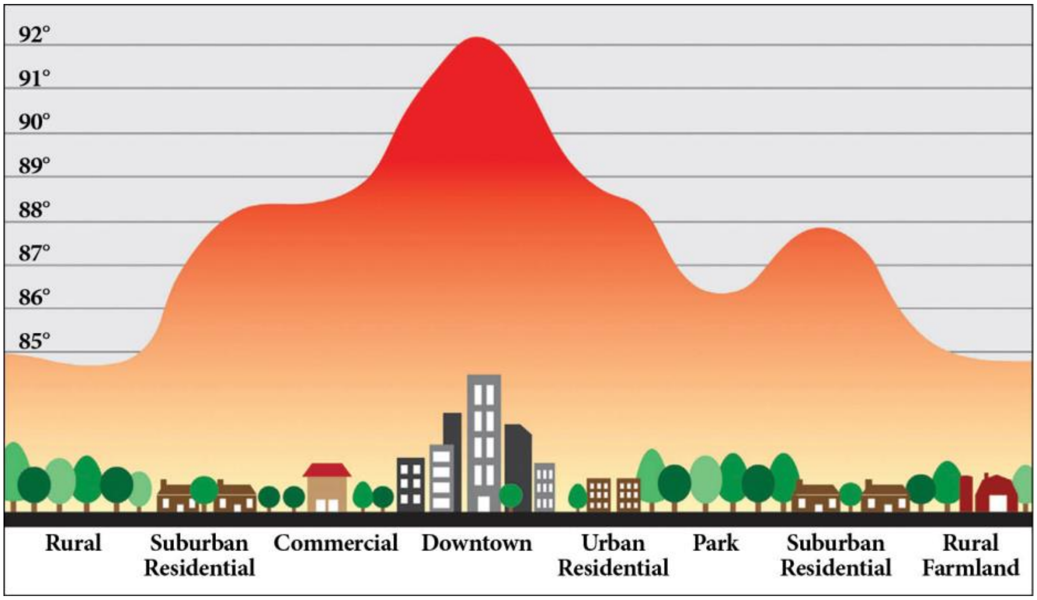
Over the years, Titanium has gained great interest in serving, to the possible extent, various industries. On one hand, as an ore mineral, titanium is world-famous in the jewelry market; its unique luster and resistivity to wear places it amongst the top tier metals that dominate this industry, such as gold and platinum. Furthermore, titanium serves a great deal in industrial products (e.g. mobile phones) and other high-performance products. This metal is very crucial in the medical field as well because it play an integral part in the production of surgical tools and technologies, in addition to being number one in prosthetics manufacturing. The attraction of titanium towards industrial products is mainly due to its strength and weight i.e. titanium possesses steel's strength with almost half of its weight, and has nearly double aluminum's strength though about 60% heavier [32]. Moreover, titanium is a key agent for the development of high-performance, low density alloys when combined with other metals, including vanadium, iron, molybdenum, and nickel. Due to their ability to withstand great temperatures, these amalgamations are of excessive interest for high-technology products, as they produce necessary parts for armories and military equipment as well as for aeronautical engines and spacecraft. On the other hand, Titanium is largely used in the form of titanium dioxide (TiO_2). It's most common application is in the paint industry as a whitening and opaque agent. Titanium dioxide brightens the paint's reflectivity. Furthermore, these characteristics, whiteness and opacity, have expanded the applications of titanium into the food, hygiene, and cosmetic industries i.e. it is added to skim milk, toothpaste, sunscreen to give them this bright white hue [32].

On a more interesting note, Titanium Dioxide plays an important role in the context of sustainable development by supporting renewable energy and efficiency. At the European scale, accomplishing the Agenda 2030 goals, in accordance with the Paris agreement, is the building block for the realization of the policies set by the European Green Deal. The EC has initiated a series of policies under the European Green Deal to assist in attaining Europe's 2030 targets, such as reducing greenhouse gases (GHG) to a minimum of 55% and achieving complete climate neutrality by 2050. Basically, the EC policies advocate for carbon neutrality of industries and the implementation of a circular economy [33]. Achieving such ambitious climate goals shall rely heavily on renewables while enhancing energy efficiency. Estimations of the environmental impact assessment on Agenda 2030 targets state an increase of renewable sources up to 40% which results in the need for energy efficiency to reach about 39% for end-user consumption and about 41% for primary consumption of energy [34]. According to what was mentioned, the transition from energy efficiency towards an energy sector dependent on renewables stresses on the need to improve technology, innovation, and infrastructure. Titanium Dioxide is key for enhancing energy efficiency, as well as the production of renewables in the following domains:

(a) Buildings and construction materials:

Titanium Dioxide is fundamental for the boost of energy efficiency and the reduction of consumed energy amount in buildings stock. This is relevant because in Europe, buildings are considered to be the greatest single energy consuming up to 40% of energy and accounts for 36% of Europe's GHG [35]. As previously mentioned, the TiO_2 pigment possesses vital components in paint products, giving it unique characteristics, such as durable white coatings, for the building's exterior as well as interior. The application of such pigment relates to energy efficiency by notably lessening interior temperature creeps, when applied on the exterior surface of a building. TiO_2 has the ability to reflect direct solar infrared rays. Consequently, coating a building with TiO_2 paints eliminates, to the extent possible, the need for internal cooling devices (e.g. Air conditioners), which saves up energy. On the other hand, several cities face the issue of the "urban heat island effect", which is stemmed by the absorption of temperatures by concrete and other construction materials i.e. Temperatures are significantly higher in urbanized cities than in rural areas. This effect can be decreased by coating surfaces with white TiO_2 paint.

Figure 6: The Urban Heat Island Effect [35]



(b) Foundation of futuristic renewables:

According to European studies, by the year 2030, renewable sources are foreseen to comprise 32% of the total global energy consumption [36]. Achieving renewable energy targets could be significantly heightened by the considerable contribution of the photocatalytic property of Titanium Dioxide. This property is strongly exploited in today's solar energy technology, and will surely be integral for their improvement in the future. To put things into perspective, a recent material, Hematene, has been unveiled by a team of international scientists, declaring that this material is prone to significantly improve solar-fuel generation [37]. Paring this material with TiO_2 nanotubes allows the extraction of photocatalytic energy from the electric charge produced; the amassed energy is for use. Other than being proven as the most efficient photo-catalyst, Titanium Dioxide is also being adopted for various projects in air cleaning and water purification.

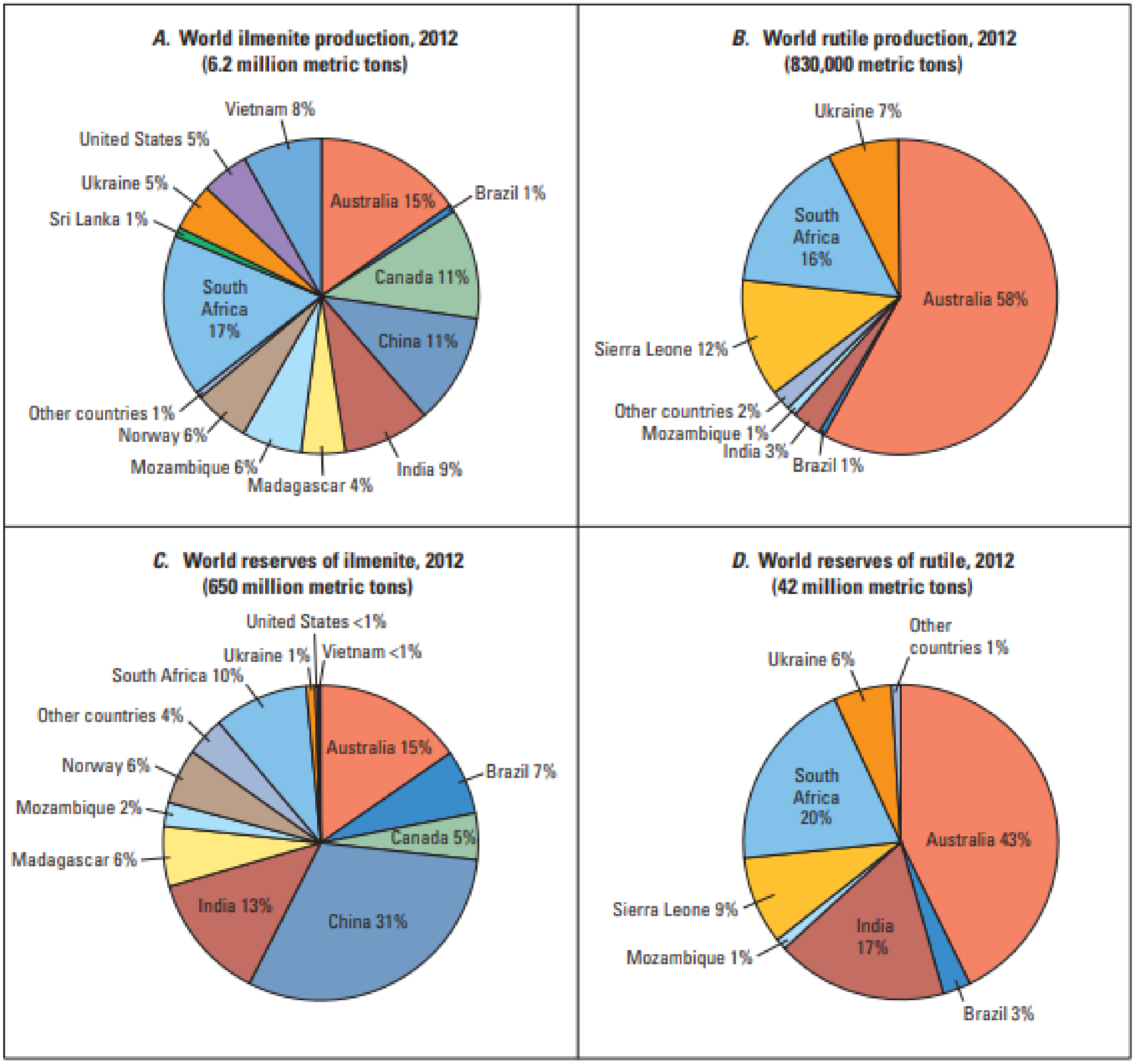
(c) Batteries innovation:

As part of the European Green Deal policies, the EC introduced regulations towards enhancing sustainable and circular battery value chains. This means that batteries are essential to Europe's transition to a circular economy and to reduce emissions. For that to occur, the battery industry shall seek to improve batteries' capacity and their durability. TiO_2 is a fundamental compound to enhance battery efficiency; it allows the extension of battery storage and their lifespan. For instance, studies in 2015 developed batteries with a TiO_2 core that showed the capability to recharge 70% of their total capacity in two minutes, while having a life-expectancy of about 20 years [38]. In addition, TiO_2 in chargeable lithium-ion batteries have been proven valuable in reversible reactions, which enables such batteries to have more durability. An extended lifetime helps in reducing the need to recycle batteries [39].

Titanium industry supply chain

Titanium is widely scattered in Earth's crust in various forms, from sedimentary concentrations to metamorphic deposits. The world's total resources of Titanium-bearing minerals (e.g. rutile, ilmenite…) are projected to be over 2 billion tons [40]. Typically, the world's titanium mineral concentrates pertain to Ilmenite and Rutile. As per the U.S Geological Survey, the world's largest Ilmenite reserves are in China, which results in it leading the world in the production of Ilmenite [40]. On the other hand, Australia dominates the Rutile industry as it produces more than 50% of the world's total Rutile production; Australia also holds the largest Rutile reserves in the world, accounting for 43% of the total reserves (Figure 7). On the European scale, only Italy, Norway, and Ukraine display economically viable resources of Titanium, with Italy containing the greatest concentrates of predominantly Rutile in metamorphic deposits. They pertain to less than 1% of the global rutile reserves, under "other countries" in Figure 7.

Figure 7: Estimated world production of Ilmenite and Rutile, 2012 [40]



It is necessary to mention that Ilmenite resources surpass Rutile resources, appointing heavy mineral sand deposits to be the largest type of titanium resource for worldwide supply. Heavy mineral sands are significantly greater than metamorphic and igneous resources [41]. Titanium mineral resource distributions are widespread in several geological settings and environments, highlighting the importance of developing modern technologies that facilitate the extraction of these minerals from unconventional mineral deposits.

Table 6: World Titanium Resources according to type of Deposit [41]

Country	Deposit type	Deposit class	Contained titanium dioxide, by primary ore mineral (million metric tons)	
			Rutile	Ilmenite/ titanomagnetite
Australia	Heavy-mineral sands	S	39.9	246
Brazil	Heavy-mineral sands	S	0.1	7
Brazil	Anatase in weathered rock	I	150	—
Cameroon	Heavy-mineral sands	S	2.9	—
Canada	Heavy minerals in oil sands	S	—	183?
Canada	Gabbro/anorthosite	I	—	>2,000
China	Heavy-mineral sands	S	0.7	22
China	Titanomagnetite in layered mafic intrusions	I	—	~52
China	Rutile in anthophyllite	M	6	—
Egypt	Heavy-mineral sands	S	0.5	—
India	Heavy-mineral sands	S	>18.0	>348
Italy	Rutile in eclogite	M	9	—
Kazakhstan	Heavy-mineral sands	S	0.3	~3
Kenya	Heavy-mineral sands	S	3	61
Madagascar	Heavy-mineral sands	S	—	60
Malawi	Heavy-mineral sands	S	>13	190
Malaysia	Heavy-mineral sands	S	—	~10
Mexico	Metasomatized anorthositic rocks	I	—	3
Mozambique	Heavy-mineral sands	S	3.2	237
Namibia	Heavy-mineral sands	S	0.6	36
New Zealand	Heavy-mineral sands	S	—	5
Norway	Gabbro/anorthosite	I	—	238
Norway	Rutile in metamorphic/metasomatic rocks	M	61	—
Russia	Titanomagnetite/ilmenite/titanite	I	—	121
Russia	Heavy-mineral sands	S	2.3	9
Senegal	Heavy-mineral sands	S	0.6	22
Sierra Leone	Rutile/ilmenite in fluvial deposits	S	10.2	5
South Africa	Heavy-mineral sands	S	4.4	82
Sri Lanka	Heavy-mineral sands	S	0.5	~12
Ukraine	Heavy-mineral sands	S	0.5	~14
Vietnam	Heavy-mineral sands	S	—	8
Total[1]			**~325**	**~3,975**

The table above demonstrates an estimated quantity of Titanium resources available worldwide. The deposits class correspond to sedimentary (S), igneous (I), and metamorphic (M) origins of occurrence, paired with the relevant type of rutile or ilmenite deposit. It is important to note that the recorded rutile deposit in eclogites tied with Italy correspond to the Piampaludo Titanium field deposits.

Legal Framework for mining heavy metals (Titanium) in Italy

The Italian mining sector became legit as of 1927 following mining ownership laws. Titanium, as well as all the heavy metals, is categorized as "First category minerals" under the Italian legal framework for mining activities. The main legal policy for the extraction of mineral activities is the Mining Law (Regio Decreto) No. 1443 of 1927. By Regio Decreto (Royal Decree) 1443/27 (Art. 2) declaring that the State owns legal rights to "First category minerals" which include all heavy metals, non-metallic minerals with industrial significance (e.g. salt, gemstones, cement marls, etc.), and energy minerals except for peat. On the other hand, the Italian State grants ownership to landowners for the extraction of "second category minerals", which are basically minerals extracted by means of quarrying (e.g. building material, quartz and silica sands, etc.), except for the common clay [42]. In addition, the extraction of maritime sands and gravel belong to the State. Regarding "first category minerals", the regions are responsible for all proficiencies concerning planning and managing these mines, under the Legislative Decree 112/98 and Constitutional Law 3/2001 [42].

In terms of exploration and extraction of minerals, relevant legislations for licensing and permits in Italy include the Presidential Decree 128 of 1959 that sets the police standards and principles for mines and quarries, the Legislative Decree 152 of 2006 which is a law framework that forces mining and quarrying activities to abide, to the extent possible, by the environmental protection concerns through Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), and Integrated Pollution Prevention and Control (IPPC), the Law n. 388, Art. 114 of 2000 that imposes the necessity of having a detailed plan for site remediation as well as recovery of the environment, Legislative Decree no. 624 of 1996 which provides protection with respect to workers' health and safety, and the Legislative Decree no. 117 of 2008 which was altered from the EC Directive 2006/21that emphasizes on the importance and need for the management and regulation of mining and quarrying wastes. An overview of all legislations relevant to Italian permitting in the active regions regarding exploration and extraction activities is found in Annex 3. Rearrangement of the Legislative Decree 104 of 2017 on updating EIA transported back the EIA processes to central levels, as in the Ministry of Environment, regarding some exploration and extraction activities with strategic and complex cases of metals and their compounds. Moreover, the National Law 56 of 2014 in Italy foresees change in competencies in all of its regions regarding Provincial Authorities, which allows extractive activities, along with the related procedures to undergo constant revision. Conversely, attention must be paid to the region of interest when controlling mining and environmental licensing measures because the Italian government adapts a decentralized regime, authorizing each region to apply their own regionally relevant laws; Each region has its own permitting protocols [42].

To outline the general procedure of permitting in Italy, the claim for a permit of exploration concerning “First Category Minerals” initiates with the submission of a request, along with all operational plans and relevant documents, to the Regional Authority, leading to the acquirement of an exploration permit, together with a complete extraction strategy prepared in agreement with the requirements established by the Municipality Mining Plan of the region [42]. Authorization of such permit shall be granted after conclusion of a preliminary EIA. In effect, Regional Laws and their ensuing amendments require that all mines undergo EIA protocols, including those located, even if partially, within forests, coastal areas, protected natural zones, spaces with historical and cultural significance, and particularly in locations neighboring Sites of Community Importance (SCI) and Special Protection Areas (SPA).

Titanium Value-Chain Comprehension:

Like in every industry, a mine initiates operation when financial profits appear promising. Mankind remains under the notion of following personal gain despite the challenges facing social advancement and environmental protection; that is, in the mining context, benefitting from a resource’s market value rather than its service to humanity. This renders Titanium resources, as well as many other socially crucial ores, scarce (Figure 8) [42]. This scarcity isn’t defined in terms of abundance in the Earth’s crust, rather in whether a certain deposit is profitable or not; the difference between resource and reserve. Therefore, the Titanium deposits are hindered to those that indicate commercial possibilities, which are confined to three commercial ores, rutile, ilmenite, and titaniferous iron ores (magnetite) despite the existence of other Titanium-bearing minerals (Table 7) [43].

Table 7: Main Titanium-Bearing Minerals [43]

Mineral	Ideal Formula	TiO_2 Content (%)
Rutile	TiO_2	92 – 98
Anatase	TiO_2	90 – 95
Brookite	TiO_2	90 – 100
Ilmenite	$FeTiO_3$	35 – 60
Leucoxene	Fe_2TiO_6	60 – 90
Perovskite	$CaTiO_3$	40 – 60
Sphene	$CaTiSiO_6$	30 – 42
Titanomagnetite	$TiFe_2O_4$	2 – 20

Figure 8: World's Major Titanium Deposits [42]

The worldwide Titanium mineral deposits are observed to have occurred in all rock-forming settings: igneous, metamorphic, and sedimentary. Some cases show significant overlap between different settings e.g. magmatic silicates and oxides with Iron and Titanium concentrates can undergo metamorphism to produce rutile, which is subsequently weathered and eroded from the original rock to be transported by water or wind to a sedimentary setting of heavy-mineral deposits. Commonly, all Titanium deposit types originate from titanium-enriched rocks as a result of a variety of geologic processes [43]. A Titanium deposit's value and potential in terms of economics and mining is defined primarily by its mineralogical composition, before its total Titanium content. Bear in mind that the economic viability and importance of a deposit depends as well on all forms of contributions to the minerology, including grain size, texture, assemblage, type, presence of traces, etc. On the other hand, the word displays shortages in high grades, high quality Ti-bearing mineral deposits (ilmenite and rutile), despite the element's large overall resources [44].

Titanium Deposits Related to Igneous Rock

Considerable Fe-Ti-oxides deposits occur from mafic incursions of varying type and age. In addition, huge, layered plutonic Anorthosite suites from the Proterozoic eon host deposits with high concentrates of ilmenite and hemo-ilmenite, though they are constrained in time, between 0.5 and 2.5 billion years. Thus, noteworthy Titanium resources within the majority of these complexes are dated to about 1 and 1.8 billion years [42]. Several, unusual mafic rocks of different types dominate the plutonic complexes, labeling these rocks as gabbro, anorthosite, troctolite, charnockite, etc. The composition and amount of pyroxene and plagioclase is distinguished amongst the aforementioned rocks. Deposits of Titaniferous-magnetite with traces of ilmenite are mainly found in intrusions of massive, layered gabbro, norite, and a lighter colored gabbro called leucogabbro. These types of rocks belong, in most cases, to the suites of Anorthosites from the Proterozoic eon [42]. These Titanium-bearing minerals are often mined for vanadium, iron, as well as titanium globally. However, some magmatic settings appear, to the extent possible, very mysterious. Fe-Ti-oxides formations in those mafic inclusions necessitate promising combinations of arrangements, oxygen transience, and crystallization process, in order to determine whether the deposit is ilmenite or titaniferous-magnetite dominant. In effect, large hemo-ilmenite occurrences are said to have resulted from early crystallization of ilmenite [45]. On the other hand, titaniferous-magnetite embedded in intrusions may be a result of late-phase iron and titanium concentrations within magmatic fluids succeeding silicate crystallizations. Consequently, the titanium minerals of the host rocks are subjected to alterations when exposed to metasomatism. Another form of titanium minerals concentrates related to igneous rocks can occur in carbonatites and igneous alkali rocks. In addition, titanium resources of high significance can be contained in excessively weathered rocks, such as laterites and bauxites [42].

Titanium Deposits Related to Metamorphic Rocks

Regarding metamorphic-related deposits, rutile stands as the mineral with the most economic potential for Titanium. However, concentrations of rutile ores in sands are restricted in volume, despite the fact that high grade ores are mostly focusing on the potential of rutile from metamorphic rocks, given that high grades ilmenite sand (more than 55% of TiO_2) are inadequately supplied [46]. Eclogite is a core focus point for high-grade rutile. It is a metamorphic rock usually formed under conditions with high pressures, composed mainly of pyroxene and garnet, typically with fewer quantities of rutile. Based on a Norwegian study, the generation of economically interesting rutile deposits requires a Ti-rich protolith, prior to metamorphism [46]. In effect, eclogite exploitation faces complications from the variability of rutile concentrates and their grain size, the reversed metamorphism of high grade rutile to titanite or ilmenite, and mostly from the occurrence of trace silicate impurities in rutile accumulations, including magnesium, calcium, aluminum and iron [46]. In addition, minor concentrates of rutile can accumulate from the deep alterations of bulk volumes of rocks when exposed to hydrothermal fluids, which typically results in depleting the parent rock in most elements while enriching it with aluminum. This process leads to the formation, after metamorphism, of kyanite ($Al_2 SiO_5$), quartz (SiO_2), and rutile. Another type of Ti-deposits related to metamorphism includes the alteration of intensely weathered rocks, such as bauxites, resulting in Al-rich rocks bearing rutile. Consequently, these Al-rich rocks create potential low-grades (about 1% of TiO_2), low-weights yet high quality rutile deposits, typically free from impurities [42]. These types of Ti-deposits are often exploited as by-products to the main, primary industrial mineral e.g. kyanite or andalusite. Moreover, rutile forms commonly in mineralized zones and aureoles of various hydrothermal, metamorphic deposits. Lastly, rutile can be produced from the breakdown reaction of Ti-bearing oxides and silicates when host rock is exposed to hydrothermal fluids with great temperatures. This phenomenon is often observed in aureoles of some porphyry-Cu-deposits, which are igneous rocks with disseminated quantities of chalcopyrite ($CuFeS_2$) and other sulfides.

Titanium Deposits Related to Coastal Shorelines and Dunes, and Older Equivalent Rocks

Titanium deposits also occur as sedimentary, eroded and weathered from a Ti-bearing parent rock. Thus, these types of deposits are subjected to low grades yet mined if sufficient high quality titanium minerals are available e.g. altered ilmenite or present rutile. However, coastal shorelines, beach placers, and sand dunes account for most of the high grade rutile and ilmenite circulating our world today. These titanium minerals are largely mined from unconsolidated heavy minerals, which are minerals with high specific gravity (usually higher than 2.85 g/cm^3). Heavy minerals concentrated in sands deposits occur when titanium minerals along with other heavy minerals display relatively great resistance to erosion from the source rock, after which they are eventually weathered and sorted before settling in fluvial, eolian, or beach facies. One should note that the presence of other heavy minerals, in addition to the ti-bearing minerals, has the capability of either enhancing or diminishing the titanium deposit e.g. the presence of zircon in the deposit is harmless and valuable for exploitation, whereas concentrations of monazite in the deposit add problems due to possible radioactivity matters for waste disposal. On another note, heavy minerals in fluvial deposits settle through rivers and streams, including deltaic and lake deposition, above sea levels. Most fluvial settings exhibit minor and relatively young deposits with heavy minerals assemblages that significantly resemble the parent rock. Oppositely, beach and eolian settings consist of more abundant, older, and active heavy minerals deposits [46]. Several productive heavy mineral sand areas present common characteristics, such as:

- The location of the deposits is on inactive continental margins coupled with highly elevated (generally greatly weathered) high grade mafic igneous and/or metamorphic surrounding source rocks.
- Sea level alterations and relatively slow sedimentation rates dominate the coastal areas.
- Transgressions, shoreline drifts, and/or high energy waves constantly rework the sands.
- Sand deposits in high topographies display characteristics of ex-barrier islands and/ or dunes

Table 8: Classification of selected Ti-mineral deposits and their economic importance [46]

Deposit class	Deposit type[1]	Typical mineralogy	Level of economic importance	Example deposits
		Magmatic (igneous and igneous related)		
I–1	Massif anorthosite	Hemo-ilmenite	1	Lac Tio, Quebec; Tellnes, Norway
I–2	Anorthosite-gabbro	Ilmenite, titanomagnetite	2	Sanford Lake district, N.Y.
I–3	Layered mafic intrusion	Ilmenite, titanomagnetite	2	Magpie, Quebec; Panzihuia, China
I–4	Troctolite/ultramafic	Ilmenite, titanomagnetite	3	Longnose, Minn.
I–5	Albititic/metasomatized	Rutile	3	Kragerø, Norway; Roseland, Va. (in part)
I–6	Alkalic/metasomatized	Perovskite, brookite, rutile	3	Iron Hill, Colo.; Magnet Cove, Ark.
I–7	Weathered alkalic rocks	Anatase	2	Catalão, Salitre, and Tapira, Brazil
I–8	Weathered anorthositic rocks	Ilmenite, rutile	4	Roseland, Va. (in part)
		Metamorphic		
M–1	Eclogite-hosted	Rutile	2	Engebøfjellet, Norway; Piampaludo, Italy
M–2	Amphibolite-hosted	Rutile	3	Daixian, China
M–3	Greenschist-hosted	Rutile	5	Dinning, Md.
M–4	Contact metasomatized anorthosite	Ilmenite, rutile	4	Roseland, Va. (in part)
M–5	Metasomatized aluminum-rich schist	Rutile	5	Evergreen, Colo.
		Hydrothermal (igneous and [or] metamorphic)		
I/M	Hydrothermal porphyry ore deposits	Rutile	3	Bingham, Utah; El Teniente, Chile
		Sedimentary-related		
S–1	Fluvial	Rutile, ilmenite	1	Mogbwemo and Sherbo River, Sierra Leone
S–2	Beach (strandline) and (or) coastal dune	Ilmenite, altered ilmenite, rutile, leucoxene	1	North Stradbroke Island, eastern Australia; Richards Bay, South Africa; Trail Ridge, Fla. (in part)
S–3	Lithified paleo-placers (fluvial and [or] beach)	Ilmenite, altered ilmenite, rutile, leucoxene	2	Bothaville, South Africa
S–4	Weathered sedimentary deposits	Altered ilmenite, leucoxene	1	Trail Ridge, Fla. (in part)

Table 8 represents the relation between the geology and mineralogy of Titanium deposits with respect to their economic value. The economic status is numerically ranked with 1 presenting great economic importance, 2 having potential to become of great importance in the foreseeable future, 3 with possible, 4 with intermediate, and 5 with low importance. It is safe to say that most economic importance pertains to sedimentary deposits, as the occurrence is relatively higher, with greater concentrations, and the extraction method is less complex.

Figure 9: Titanium Dioxide Content in Titanium Deposits of different Types [46]

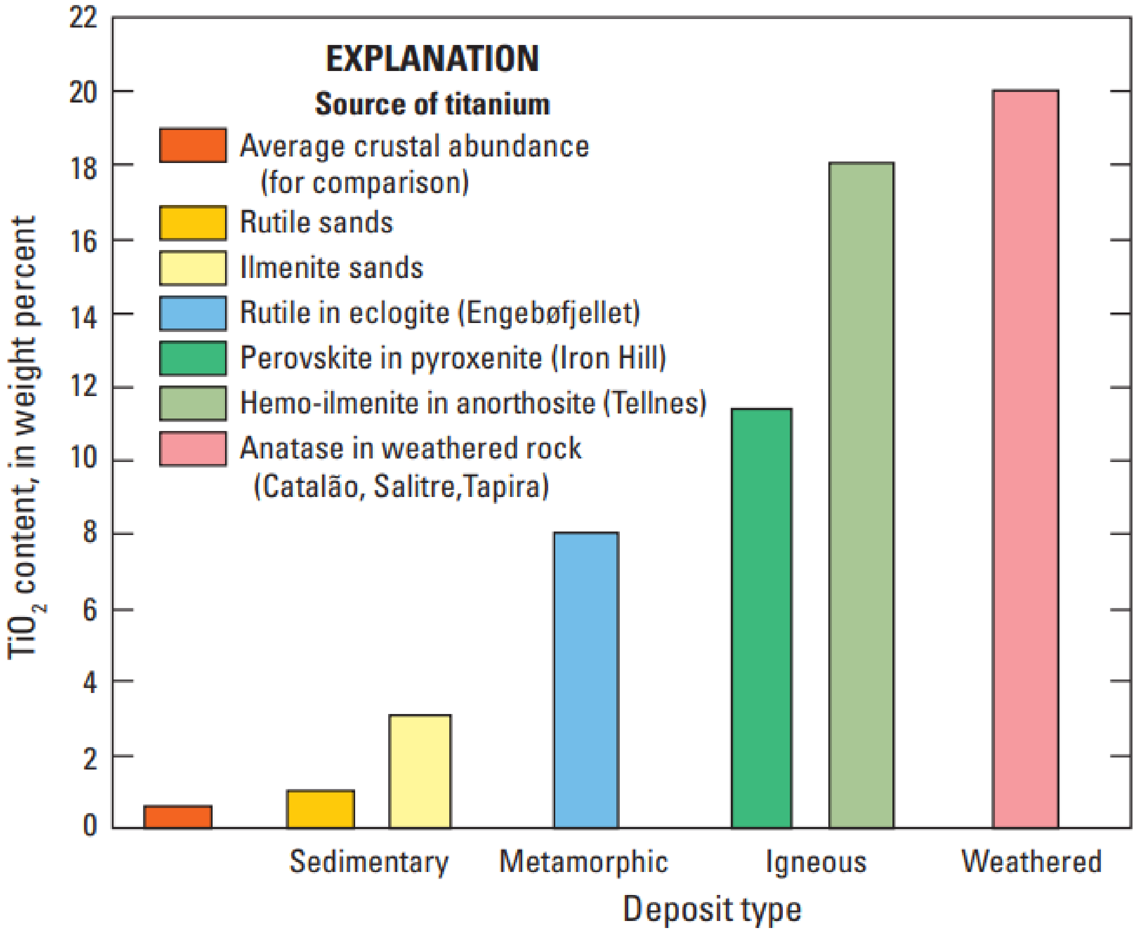
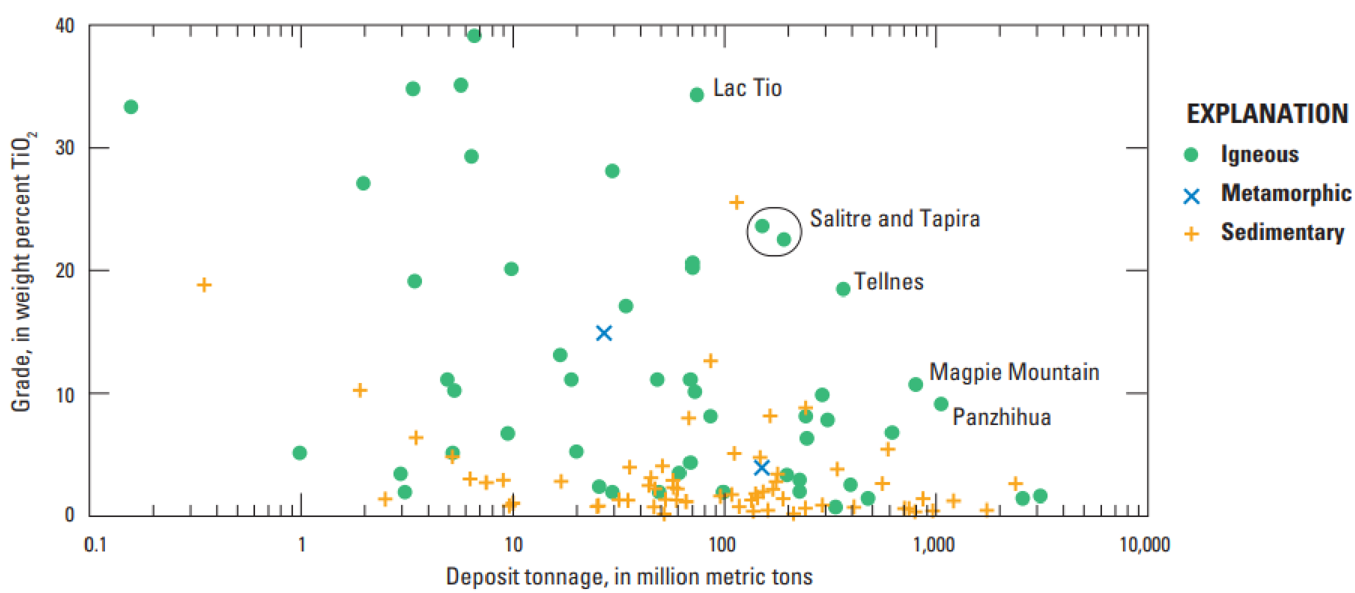


Figure 10: Titanium Dioxide Grade in relation to Tonnage by Deposit Type [46]



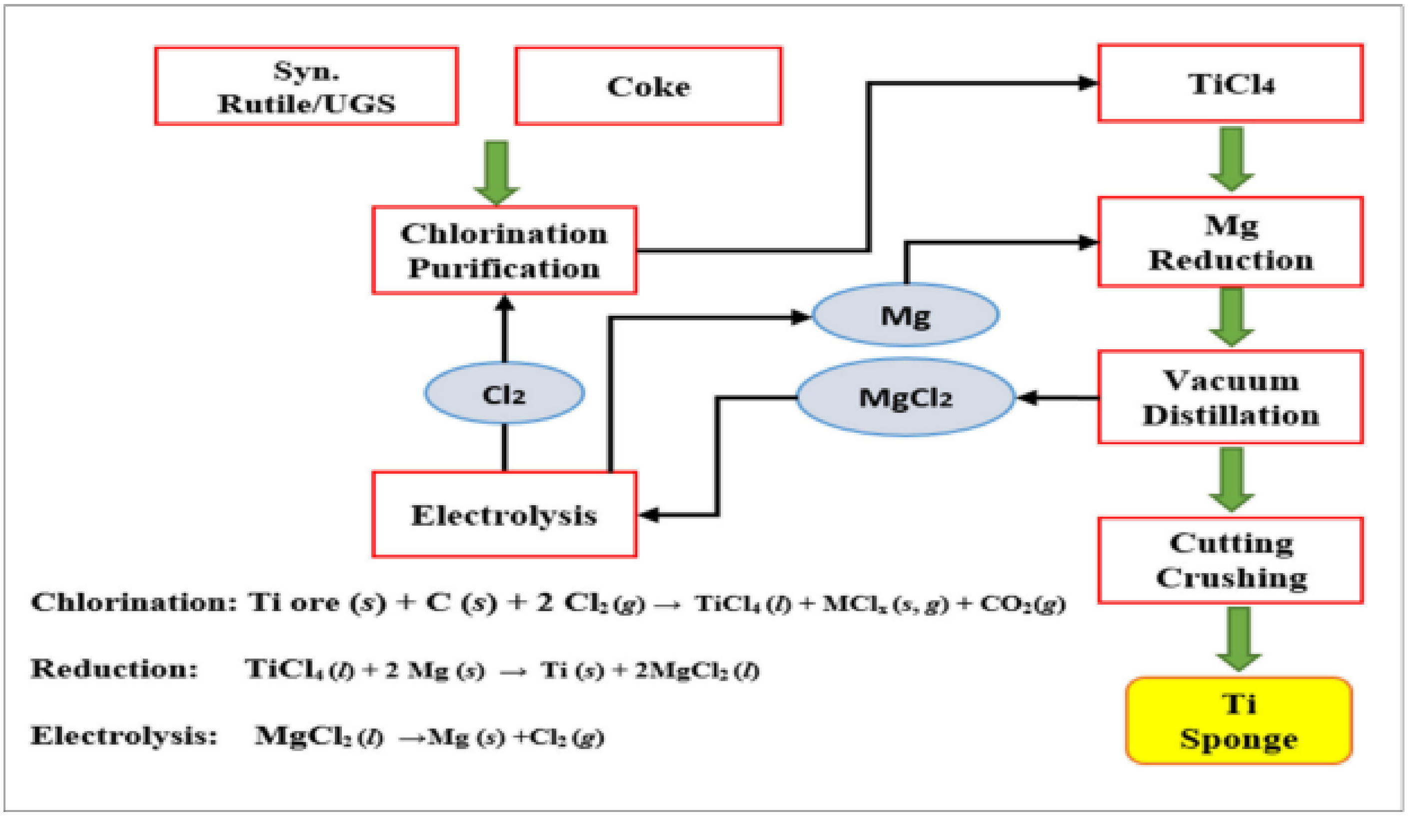
Titanium Production and Processing Method

Since Titanium is an economically attractive element, its exploitation is very much sought after. Ti-bearing minerals can be mined as primary products, co-products, and by-products depending on the type of deposit. Ideally, for Titanium minerals to be extracted as primary products, their concentrations typically needs to exhibit high grades and high quality. This is primarily observed with rutile dominated deposits, usually in igneous or metamorphic settings. However, some mines extract Titanium from ilmenites as a primary product, in which these deposits possess relatively fair economic attraction. From a mining perspective, open-pit is generally the most favorable method of excavating; it allows fast rates of production at relatively lower costs. Thus, Titanium is mined as a primary product when found in large concentrations and high grades, in rutile and ilmenite in some cases, deposited in placers. The preferred mining option with great economic viability in that case is open-pit method by mechanical excavation e.g. excavation via bucket wheel (Figure 11). In the case where rutile is present in compact, hard rocks, the preferred mining method is still open-pit, but by drill and blast; this option remains economic but is relatively slower due to cyclic operations. In addition, leucoxene-rich sand deposits also exploit Titanium as a primary product because it consists of more than 70% concentrations of TiO_2. Alternatively, Titanium is also mined as co- and by-products when present in perovskite or sphene. These Titanium-bearing minerals consist of fair concentrations of TiO_2, and are often associated with REE-rich minerals, such as monazite and xenotime. REE are often difficult to extract with proper economic interest; thus, they are commonly mined with other minerals, such as perovskite or sphene, for more resource efficiency. Furthermore, these minerals are highly sought after in certain industries e.g. sphene has great interest in the jewelry sector.

Figure 11: Bucket-Wheel Titanium Excavation [46]

Subsequently, Titanium processing renders its extraction more difficult. The method of mining can always be optimized, yet the commercial production method currently adopted follows the Kroll process. The Kroll process maximizes production and efficiency; however, it is cyclic, requires intensive energy and labor, and functions under stern conditions making the process relatively expensive. For this purpose, many on-going, global researches are determining new ways of Titanium extraction from its origin. On another note, there are several other methods of Titanium production to a metal powder. Therefore, Ti-powder is produced from the extractive process that generates primary metals, mainly through the use of Ti-based feeding material, such as Titanium dioxide (TiO_2) or Titanium tetrachloride ($TiCl_4$). As a result, Titanium powder extracted as a metal product is manufactured from purified TiO_2, $TiCl_4$, or the synthetic version of ilmenite, known as titanium slag with a TiO_2 composition greater than 90%. This mineral category also includes rutile as well as its synthetic model. Thus, their standard used methods of processing are thermochemical or electrochemical. The aforementioned Kroll process is a thermochemical processing method for the production of primary Titanium metals (Figure 12). Another standard method is the Hunter process.

Figure 12: Kroll Process for Titanium Sponge Production [28]



The process basically consists of injecting magnesium metal, as a reducing agent, into a retort heated to about 800 – 900℃, containing argon. Consequently, the impure oxides traced in the Titanium slag is chlorinated in the process, which produces refined $TiCl_4$ through purifying it even before the introduction of the magnesium agent [48]. The resulting sponge contains traces of residual $MgCl_2$ in its pores, despite undergoing drainage during the reduction of the excessive magnesium [49]. The residual magnesium and $MgCl_2$ are then detached via helium sweep before exposure to leaching. However, the final sponge must undergo decommissioning due to the contaminants present in the autoclave barriers [48]. As mentioned earlier, this metal purification method is costly, as estimates state that 70% of the total consumed energy is devoted to distillation and production of the metallic sponge. The costs of extraction and reductants shall also be taken into consideration [49]. Nevertheless, this cost is worth it with respect to the metal's criticality for our society, environment, and economy. In fact, Titanium's market price in 2018 was 4,800$/ton, a rise of about 14% from 2017, and is expected to continue soaring [50].

Piampaludo Field Deposits

Piampaludo site deposits were first discovered in 1975, as a Titanium prospect project. The deposits are located in Piampaludo; a very small village consisting of approximately 60 to 70 residents in the region of Liguria, Italy. To be more specific, Piampaludo is part of the Sassello municipality, under the province of Savona, in the Liguria region. Situated at an altitude of 857 meters above sea level, this tiny village occupies one of the largest mineral deposits of titanium dioxide in Europe, known as the Piampaludo field, and sometimes referred to as Monte Antenna field (Figure 13).

Figure 13: The Piampaludo Field (44°28'36.42"N, 8°35'42.45"E)

Piampaludo deposits are found close to the Sassello and Urbe provinces, corresponding to the mountain chains of Monte Tariné and Monte Antenna. The Titanium ore of the said field is found in rutile concentrations of the Voltri Massif within the Southeastern terminal unit of the Ligurian Alps. As observed in Figure 13, the Titanium deposits are associated with the eclogites (in light blue). The Voltri unit is integrated in the Western Alps mountain chain, located in its Ligurian-Piemontese unit, north-east of Italy (Figure 14). It is the largest metamorphic ophiolite massif of the Alpine-Apennine chain. The unit consists of metamorphic rocks, primarily ophiolites with meta-sediments and portions of the sub-continental lithospheric section of the mantle [52]. The metamorphic ophiolitic rocks are composed of metagabbro, serpentinite, and metabasite linked with minor calcshist, as well as traces of mica-schist and quartz-schist. Furthermore, the lithospheric mantle rock unit contains ultramafic igneous rocks, such as harzburgite and lherzolite in addition to minor concentrations of pyroxenite and dunite [52].

The Voltri unit is clearly complex and metamorphosed under high temperatures and pressures conditions, entering into eclogite metamorphic facies. According to many studies, the unit reached peak conditions which indicate pressures of approximately 18 to 22 kbar and temperatures of about 500-600 ℃, typical conditions of the eclogite facies [53]. These settings generally produce metagabbros rich in rutile, garnet, Na-amphiboles, and Fe-rich minerals, which are found in the Voltri unit. The formation of rutile allowed the rock body to become a Titanium ore. The unit displays metamorphic events that are related to the greenschist facies, which are said to have later on re-equilibrated the original assemblages [52]. Additionally, the Voltri unit exhibits various deformation events throughout its time. The original structure corresponds to the eclogite facies foliation associated with high pressure stage of metamorphism, and display isoclinal folding with discontinuity through the outcrops [54]. Later events have deformed the original structure, creating more folds and fault zones that developed during metamorphic conditions related to the greenschist facies. The Voltri unit is dated between the Jurassic and the Cretaceous period, yet the Piampaludo deposits belong to the Cretaceous through Oligocene time period. The formations composing the Voltri metamorphic unit are described in Table 9.

Table 9: Geological Composition of the Voltri unit [52]

Formation	Location	Geology	Structure
Monte Tobbio Peridotites	Northeastern part of Voltri	Serpentinized peridotite + lherzolite + harzburgitic bodies + dunite lenses + bands of pyroxenite	Remnant mantle texture, mainly tectonic foliations
Bric del Dente Serpentinites	Dominant lithology of the Voltri Unit	Serpentinite + serpentine-schist + antigorite, magnetite + chlorite + olivine + diopside + tremolite + ankerite + Ti-clinohumite	Relic texture of the original peridotite. Multiple folds with shear bands
Colma Metagabbros	Southern part of the Voltri unit	Leucocratic metagabbro + garnet + Cr-mica + omphacite + glaucophane + albite + tremolite + Mg-chlorite + epidote + traces of white mica + titanite + talc + oxydes	Relic eclogitic paragenesis
Rossiglione Metabasites	Southeastern part of the Voltri unit	Ca-amphibole + chlorite + albite + epidote + minor Fe-Ti oxides + titanite + talc + biotite + calcite + white mica. Local Na-amphibole + rutile + garnet	Layered or foliated textures of melanocratic and leucocratic facies. Original textures erased by metamorphism and deformation
Turchino Calcschists	Western part of the Voltri unit	Micaschist + quartz-micaschist + carbonate schist with quartz + white mica + calcite + chlorite + biotite + pyrite. Local garnet + chloritoid + mica	Re-equilibrated green-schist facies conditions. Different deformational events across all outcrops

Figure 14: Simplified Geologic map of the Voltri Unit [52]

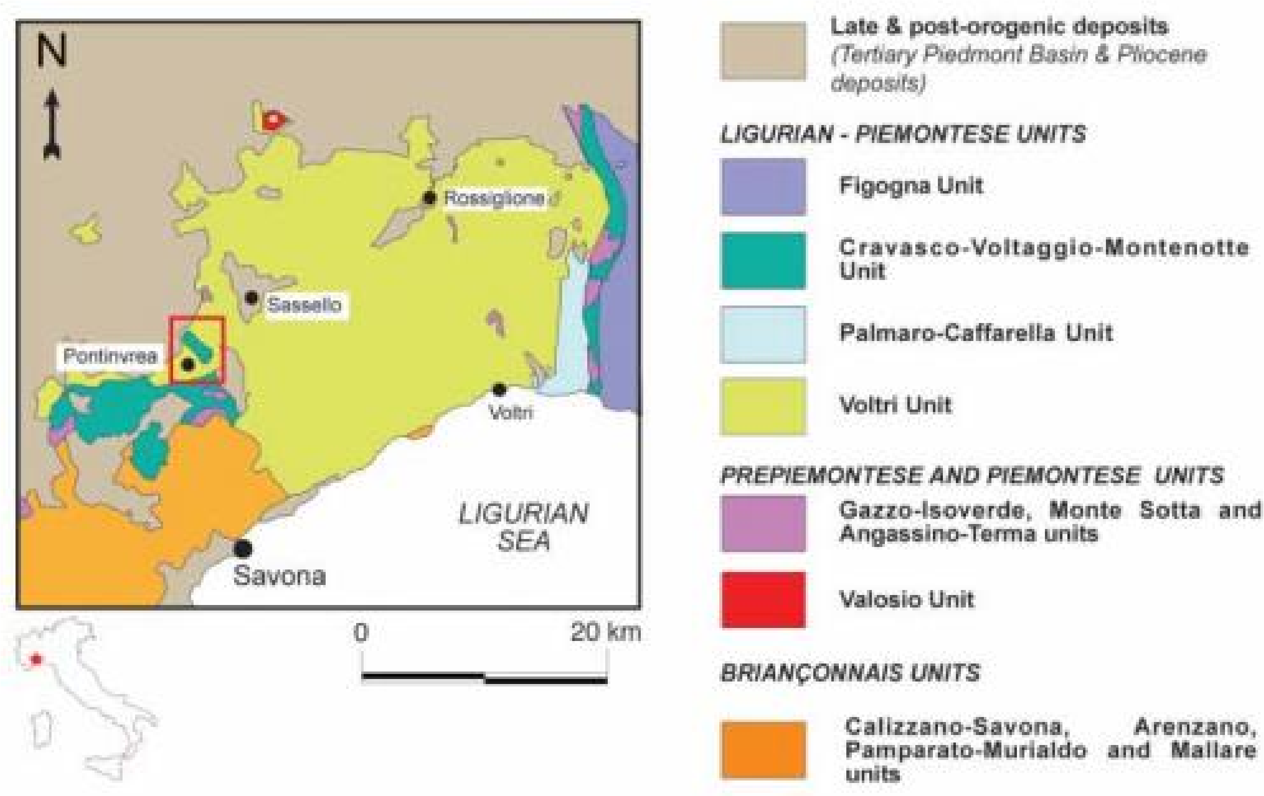


Figure 15: Simplified Geologic map of the area under study, Piampaludo [56]

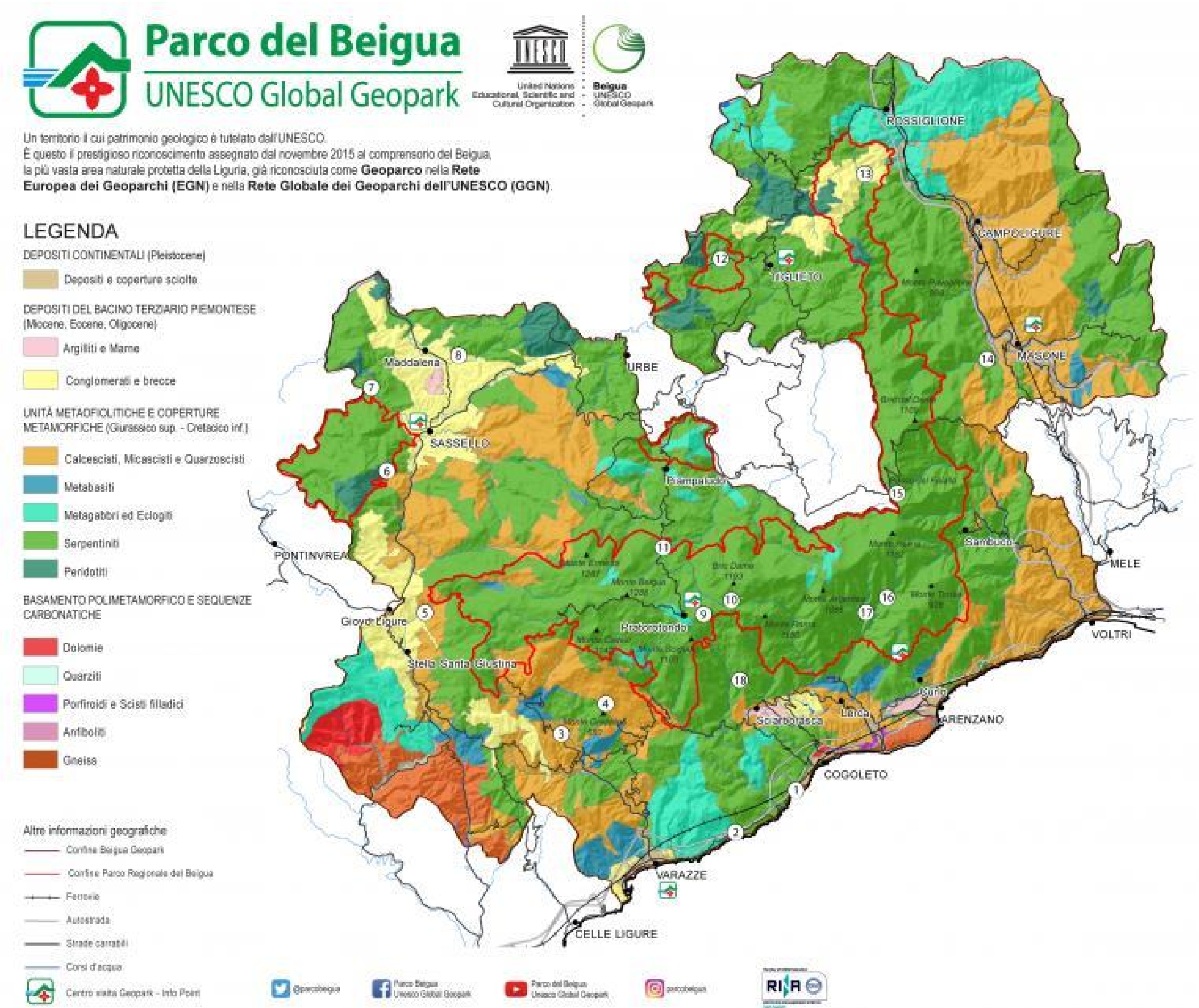
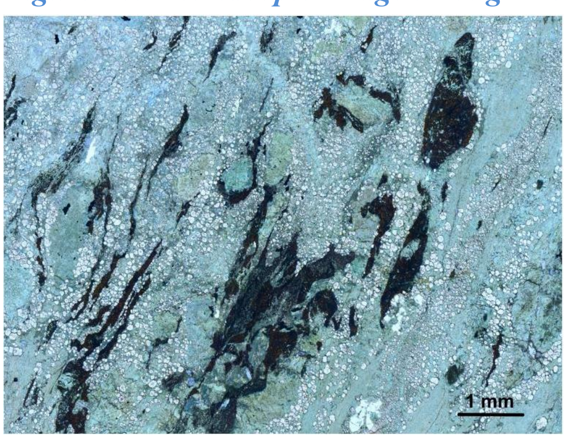


Figure 16: Microscopic Image through Eclogite under Transmitted Polarized Light



The blackish dark brown aggregates observed in the image above correspond to rutile, whereas the omfacite is in green. Garnet and glaucophane are represented by rounded pinkish granules and light blue, respectively [55].

Piampaludo Titanium Ore

The Piampaludo Titanium-ore deposits have been a point of interest and focus since the 1970's. Several studies held around the time of discovery prove that the deposit consists of mineralized masses of rutile concentrated within eclogitic rocks. These eclogites have emerged at high elevations corresponding to the mountain chains of Monte Antenna and Monte Tariné, with the respective altitudes of 670 and 930 meters above sea level. As previously mentioned, the Piampaludo eclogites have formed under high pressures (18-22 kbar); these metamorphic rocks mainly consist of sodium, aluminum, calcium, iron, and magnesium silicates, in addition to pyroxenes, glaucophane, and garnet. The site's eclogites are the product of deformations of the oceanic crust, with the presence of ophiolites and meta-sediments that are covered by Oligocene clastic sediments from the Tertiary Piedmontese Basin. Rutile, on the other hand, is the main accessory mineral in the Piampaludo field, present in millimeters and rarely as aggregates of an order of centimeters. Rutile crystals are detected at micrometric dimensions, approximately 5 to 100 µm, with varying colors from brown to yellow and a metallic luster [57]. According to studies conducted in the 1980's, the Piampaludo eclogites comprise, on average, a TiO_2 concentration of 6% (ore grade), with enrichments up to 12%. As a result, the rutile reserve established at the Piampaludo area is about 9 million tons [57]. However, other estimates state that this reserve can be up to 20 million tons [58]. Based on these assessments, the Piampaludo field surely belongs to the greatest Titanium deposits in Europe.

These estimates have developed from several field and laboratory studies. Moreover, preliminary developments took place in Piampaludo, as part of a prospect project in 1985 [51]. The aforementioned investigative studies encompass geophysical, geochemical, and geological mapping analyses that are supported by on field surveys and developments, including core-drilling, surface trenching, and a shaft. In fact, a former professor at the Politecnico di Torino (R. Mancini) had undertaken specific studies on the subject of possible exploitation of the orebody, and mentioned that special techniques must be implemented in the case of ore mining at Piampaludo, due to malfunctions and quick wear of the tools and drill-bits observed at high rates (complete exhaustion of tools within the span of 4 hours) while preforming cores; this fast wear is caused by the abrasive strength of the said eclogites [59]. The eclogites of the area are very compact and hard. Moreover, results show that rutile is present in ore-aggregates of about 1-2 mm thick at 40 to 90% concentrations, where the majority is paralleled with the orientation of the foliation [51]. The preliminary investigation of the field determined the ore body as massive, highly fractured, and displays low schistosity [51]. Geophysical and geological data demonstrate that the ore body's morphology is a large concordant lens, dipping 20° to the south [51]. Additionally, field tests and researches project that the Titanium reserve extends to over 400 million tons at elevations deeper than 500 meters [58].

Therefore, it is safe to say with intermediate to high confidence that sufficient data and information have been collected and assessed to properly estimate the ore grade and tonnage. On another note, studies show that the ore body contains relatively fair quantities of garnet, accounting for approximately 30 to 40% of the weight (Figure 17) [57]. As a result, the garnet available within the deposits can be mined as a potential secondary product to rutile; this improves the economic interest of the Piampaludo field, as garnet is highly opted in the jewelry sector.

Figure 17: Eclogites of Piampaludo observed under microscope [60]

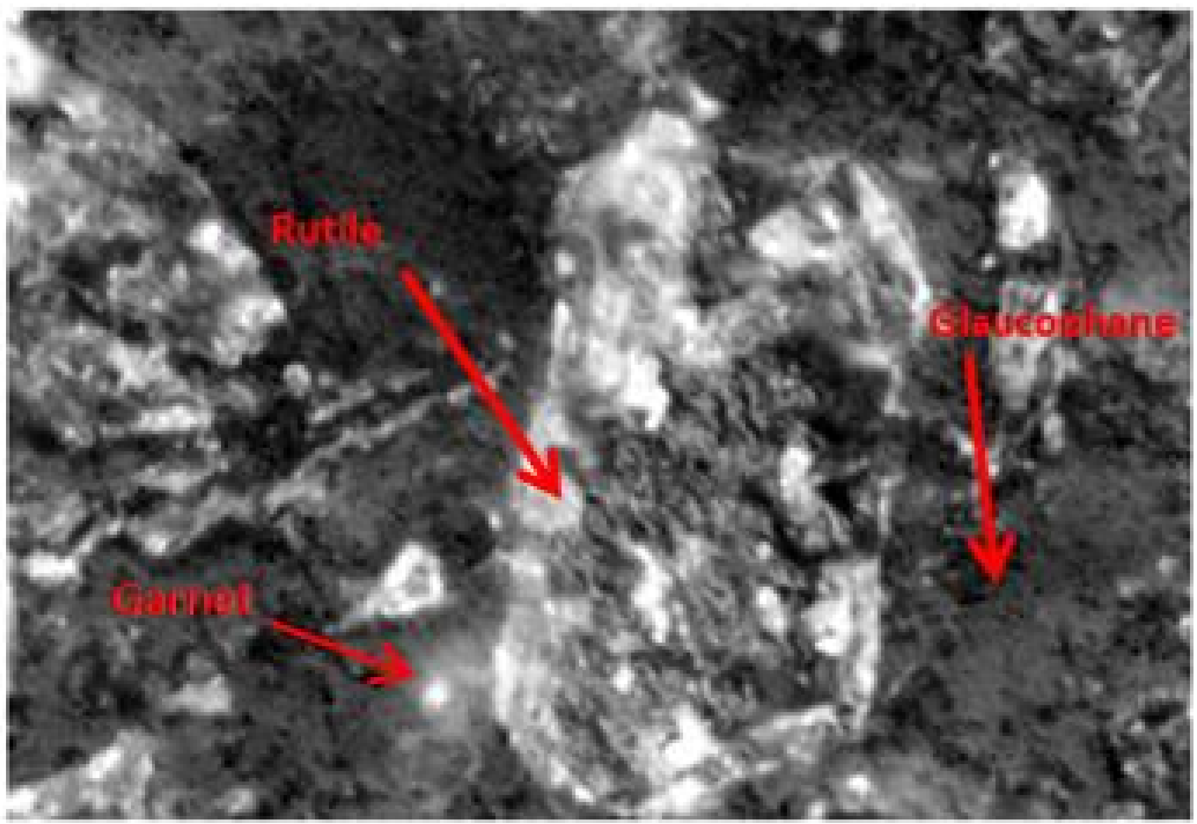


Table 10: Summary of Piampaludo Titanium Deposit Characteristics

Location	Piampaludo, Sassello, Savona, Liguria, Italy
Unit	Voltri Unit
Formation	Rossiglione Metabasites?
Age	Jurassic to Cretaceous
Overburden	Oligocene clastic sediments
Geologic Setting	Metamorphosed Oceanic Crust, Ophiolites and Metasediments
Rock Type	Metamorphic Rocks
Host Rocks	Eclogites
Formation Conditions	T= 500 – 600˚C P= 18-22 kbar
Physical Features	Massive, very compact, hard rocks
Ore Mineral	Rutile
Ore Mineral Chemistry	TiO_2
Ore Occurrence	Aggregates about 1-2 mm wide
Ore Weight	9 million tons
Ore Grade	6% (enrichments up to 12%)
Ore Morphology	Large Concordant Lens
Ore Orientation	20˚Dip to the South
Secondary Minerals	Garnet, Glaucophane, Titanite, Ilmenite, Serpentine, Talc, Magnetite, Actinolite

Preliminary Mining Plan by C.E.T Srl

In 1976, the Italian Ministry of Industry granted mining concession on the Piampaludo field to Mineraria Italiana Srl in which it was later transferred to Compagnia Europea per il Titanio (C.E.T Srl) in 1985. During the concession period, the company has performed preliminary feasibility studies in addition to developing a mining plan. The preliminary studies included surface development, such as adits and trenches. Moreover, the investigative tests were based on adequate rounds of drill-holes and coring which led to acquire substantial data for geophysical and geochemical analyses. Geological mapping of the Piampaludo field has been conducted throughout the studies. It is noteworthy to mention that the preliminary development included the excavation of a shaft, mainly for exploratory purposes which solidified test results.

In addition to tests and estimates determined by prior studies and the previous company, C.E.T Srl has collected sufficient data and ore information to estimate ore-grade and quantities with moderate to high confidence. In effect, C.E.T Srl has generated a detailed mining plan for rutile production with garnet as a secondary commodity, which included production rates, mine life predictions, economics factors, product transportation, and waste disposal systems (Table 11). The proposed mining plan envisage a mine lifespan of 90 years with steady production rates of 10,000 tons per day, where rutile production equates to 163, 240 tons per year, with excavation depths up to 500 meters. On a different note, tailings, including the garnet sand, were provisioned to be transported through a gravity-flow tunnel of approximately 3 km to the littoral of Liguria, at flowrates reaching 9,400 tons per day.

Table 11: Mining Plan for Piampaludo Proposed by C.E.T Srl

C.E.T Srl Proposed Mining Plan as part of the Piampaludo Prospect Project	
Type of Mining	Surface
Mining Method	Open Pit
Mining Technique	Drill & Blast
Surface Area	90 Hectares
Maximum Pit Slope	60˚
Operating Days per Year	265
Operating Shifts per Day	2 shifts of 8 hours each
Production	10,000 t ore per day
Production Unit Cost	1.37 $/t ore*
Waste Rock	48.4 %
Ore Mining Features	
Ore Hardness	Hard Rocks
Length	~ 1,800 meters
Width	500 meters
Thickness	300 meters
Wall-Rock Alteration	None
Ore Control	Fracturing
Latest Ore Record	1991

***Subject to conversion into today's market price**

Piampaludo Project Classification, according to UNFC

G2+G3 classification on the G Axis, the Degree of Confidence

The geology of the Piampaludo field, as well as the Titanium mineralization is well studied and known. The extensive research and mapping of the region have strengthened the level of knowledge of the area. Substantial tests have been held on field and laboratories for the estimation of product grade, quantity, and weight. Sufficient numbers of drilling were performed, in addition to geophysical and geochemical analysis, and geological surveys. It should be noted that the Piampaludo field was a target of prospect projects and has been subjected to exploration studies. Many of these data are accessible by the public. Although Piampaludo remains a prospect project, and thus quantities should be classified as G4 according to UNFC-2019, product quantity estimates associated with the prospect project are evaluated with tangible tests and developments, allowing them to be categorized with high to moderate degrees of confidence.

In addition, the Titanium quantities have high probabilities (about 90%) to equate the forecasted amounts, whereas garnet estimates are considered with lesser certainty due to fewer evaluations, rendering its estimate moderate (about 50%). However, one must note that these quantity estimates are based on data and assessments lastly updated in 1991. Therefore, following a conservative approach, the Piampaludo project is given a G2+G3 classification on the G axis.

The product quantities can be estimated at higher degrees of confidence with further, more recent data acquisition and analyses, preferably with the application of modern, more precise detection tools, technologies and prospecting methods.

Social and Environmental Constraints Facing the Piampaludo Deposits

Despite the economic attractiveness emanated by the Titanium commodity of the Piampaludo field, operation still hasn’t taken place since its discovery. The said field is located in a naturally preserved area which raises social and environmental limitations when it comes to excavation. These restrictions have evolved from the common perspective society has on mining, which is associated with damaging the landscape and ecologic environment while excavating; this is the case fronting the Piampaludo site deposits. Mining activities and exploration have ceased in Piampaludo after the region was included in the Beigua Natural Park in 1995.

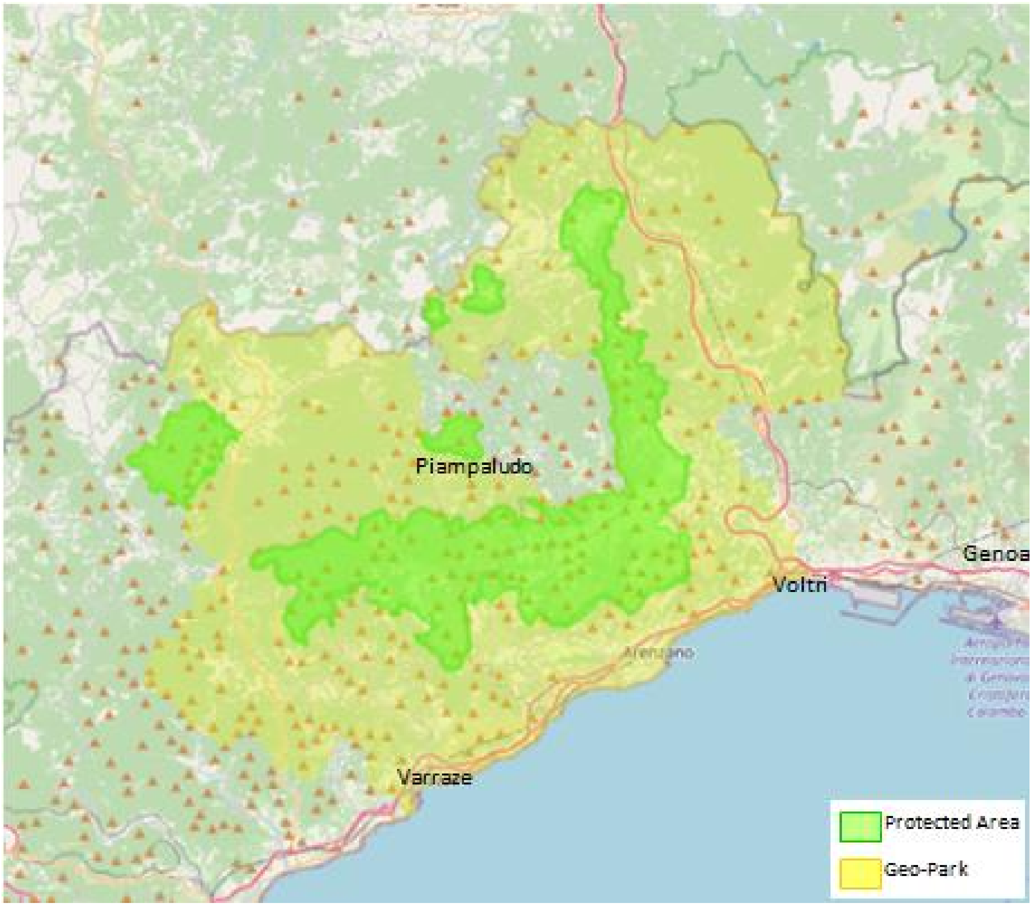
The Beigua Park is a regional natural park located in Liguria. It is one of the largest protected realms in Italy, rich in naturally preserved geologic features, from outstanding rock outcrops to fossil deposits. The geologic heritage exhibited at the Beigua Park has gained great interest, which endorsed the park to become recognized as a European and Global Geo-Park by 2005. Additionally, in 2015 the park was awarded to join the esteemed list of the United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Geo-Parks. In effect, the Beigua Geo-Park incorporated within its territory the entire area labeled as the Beigua Regional Natural Park, as well as a wide portion of areas linked with the park. The Beigua Geo-Park expands to two provinces, Savona and Genova, covering up to ten municipalities where nine of which are entirely included. The whole territory of the Geo-Park equates to over 39,000 hectares (Figure 18). From a scientific point of view, the Beigua Geo-Park is to be proved extremely important in the reconstruction of the Italian geologic history in addition to the understanding of the relation between the Alpine Mountain chain and the Apennines Mountains. The Beigua Geo-Park aims at conserving geologic history as part of safeguarding the natural heritage unveiled by the area; this strategy intends to protect environmental resources through management means with adequate social and economic development, leading to the preservation of the park's geodiversity.

On the other hand, the Beigua Regional Park belongs to the Natura 2000 Network, a European network that aims at ensuring longstanding survival of Europe's threatened species and rare habitats registered in the Birds and the Habitats Directives. It is important to note that protected areas in the Italian territory serve to conserve natural resources in coherence with socio-economic development of the public, according to the law on protected areas (L. 394/91). Bounded between mountains and coast, the Beigua Geo-Park is home to multiple ecosystems, rich in fauna and flora. The biodiversity at the region is significant, as it is home to great numbers of rare birds' species. Amongst the 103 identified bird species, 15 of which are scare and 18 are on the margin of rarity. In addition, Beigua is rich with majestic birds such as golden eagles and sparrow hawks. The region is considered as an important bird area. The forest and aquatic ecosystems at the park are also home to many other animals, including wolves, wild boars, amphibious species, and fish. Moreover, the region presents 26 different types of environmental facies, regarded by several vegetal units. In fact, the flora in Beigua identifies 1130 taxa, which is rather significantly high. There are some substantial wetlands at the Beigua Park that are important environmental settings which represent major natural values and ecosystems. These settings are enriched with many living organisms placed in scarce micro-environments within the frame of the area.

The geodiversity and biodiversity present at the Beigua Natural Park have raised substantial social and environmental concerns regarding the preservation of the landscapes and ecosystems. The park has also become a touristic landmark, with geo-tourism museums and centers. Another aspect considered socially is the historical interests available at the park e.g. some roman engravings and paved stones have been located. For these purposes, several opposing associations, including the Liguria region, the World Wildlife Fund (WWF) of Savona, the Beigua Park Authority and neighboring municipalities have contested against any disturbance activities of the park, such as mining, over the past 35 years.

In addition, Piampaludo's field deposits are partially (about 50%) interfering with a Natura 2000 realm. Consequently, the accumulation of these social and environmental contingencies has delayed social consent due to the lack of acceptance by the public and the environmental, ecologic impact of mining. In effect, legal actions have taken place various times between stakeholders. Thus, Piampaludo's Titanium deposit is put on hold for exploitation.

Figure 18: The Beigua Geo-Park [56]



One should note that according to the EC, it is possible to undergo mineral exploration in particular Natura 2000 sites without necessarily disturbing the ecosystem's resiliency and the entire integrity of the area. This is generally achieved through strategic planning, early on in the planning stages, which is an approach adopted by public establishments, often in consultation with all stakeholders, to guide them towards securing an alignment with sustainable development policies for the area [63]. This tool has been proven effective in identifying, mitigating, and lessening potential impacts on the ecosystem and wildlife. As a result, projects carrying out strategic plans face less challenges and delays from socio-environmental constraints due to transparency of the development framework. In the context of mineral extractive industries, strategic planning is advised to comprise detailed geologic maps for a comprehensive understanding on the available minerals e.g. whether the mineral can be commercially extracted. This investigation is commonly exploited through EIA and SEA. Strategic planning also includes rehabilitation procedures at the end of a mine's life, which aim at re-establishing and improving the natural environment and biodiversity [63].

E2 classification on the E Axis, the Environmental-Socio-Economic Viability

The exploration permit of the Piampaludo project was granted by the Regional Council of Liguria to C.E.T srl in 2021 (Table 12). Initially, the project was claimed via mining concession to Mineraria Italiana Srl valid for 20 years, first granted in 1976 before getting transferred in 1985 to the current stakeholders C.E.T srl. The Cuneo-based company C.E.T srl, has been struggling with licensing and permitting since 1991, ever since the request for an additional 20 years of mining consent to the Italian Ministry of Industry. The challenges objecting C.E.T's requests are primarily caused by social and environmental oppositions [61]. On the contrary, the area in question has been the subject of numerous regulatory interventions for protection, first of all the creation of the Beigua Regional Natural Park, established by regional law no.16 of 9 April 1985. Subsequently, the regional law of Liguria n.12/95 regulated and strengthened its protection and protection functions throughout the territory included in the Park and which includes approximately 50% of Mount Tarinè (now referred to as the Piampaludo Field), which was the original potential mining basin, which for over 35 years has instead become a protected environment for the protection of landscape and ecosystem existing there [61]. Having said that, and in relation to the evolution of previous events, the dispute originates with the request of the C.E.T in the autumn of 2014, which aimed at obtaining a new mining research permit for titanium, garnet and associated minerals [62].

Today the Piampaludo project consists of a claim for exploration under "act n. 1211 of 02/26/2021", limited to the area of approximately 229 ha outside the territory of the Beigua Regional Natural Park. The company has exclusivity of exploration. The exploration permit allows C.E.T to carry out preliminary investigations aimed at evaluating the distribution, areal and surface, as well as defining the concentrations of rutile present in the indicated area [62]. This permit is valid until 2024.

From an environmental perspective, the proposed exploration activities and research by C.E.T are planned not to modify the existing state of the area. These activities intend to produce insignificant and minimal negative impacts on the natural environment and landscape; they will not interfere with the natural processes present on site as well as not involve destructive methods or sampling of mineral, vegetation or animal samples, with geological and structural surveys carried out on foot, using only existing tracks and paths, with permitted access [60]. C.E.T may be subjected to undertake SEA and EIA to identify environmental consequences. From another perspective, if mining were to take place, the area won't be harmed, to the extent possible, as new mining techniques have evolved to become more environmentally-friendly. However, the presence of a processing plant may possibly raise environmental issues.

As per the economic point of view, there is no doubt that the Titanium deposits of the Piampaludo field display great economic interest, given the ore-grade and weights. Estimates foresee that exploitation of Piampaludo brings about 500 million euros in royalties to the Liguria Region, against a deposit whose value was estimated between 400 and 600 billion euros. According to today's value of rutile per ton and the Piampaludo rutile content, estimates value the deposit to at least 120 billion euros [61].

Currently, the development of the Piampaludo project is not certain to be environmentally-socially-economically viable due to insufficient information to impede the project. However, assumptions lead to a sensible outlook of environmental-socio-economic viability with the given conditions. Thus, the project is classified as E2 on the E axis. Table 12 depicts how the socio-environmental-economic viability is affected through main events challenging the project.

Table 12: Permeting Timeline for the Piampaludo Project with respect to E axis shifts

Period	Event	E axis Category
1976	Mineraria Italiana Srl granted mining concession	E1.3
1985	Mining concession transferred to C.E.T srl	E1.3
1991	C.E.T srl request 20 years concession renewal from the Ministry of Industry, no answer to date	E2
1995	Area included in the Beigua Park any mining or related activity was interrupted	E3.3
2014	Court objects to C.E.T's request to obtain new mining research permit	E3.3
2015	Court objects to C.E.T's appeal for the annulment of the inadmissibility of the application relating to the mining research activity	E3.3
2015	Court rejects C.E.T's request to activate the procedure for the EIA for geological surveys	E3.3
2020	Court rejects C.E.T's plea to challenge court's decision, entrusting the recourse to Violation and/or False Application of Law	E3.3
2021	Regional Council of Liguria confers in favor of C.E.T, granting the research permit on the mainland of solid minerals (Titanium, garnet and associated minerals) for 3 years	E2

F2.2 classification on the F Axis, the Technical Feasibility

The preliminary planning done by C.E.T srl include the necessary prefeasibility and scoping studies, which are being further elaborated and ongoing with the recently claimed exploration concession. Although Piampaludo is an exploration project, the preliminary studies provide sufficient data on the possibility for advanced developments with clear resource definition, rendering it to a more advanced category on the technical feasibility. However, more studies are yet needed to be in accord with the technical feasibility of the project. At the moment, activities for advanced development at Piampaludo are awaiting justification by sustainable viability, meaning that development may be held off by a significant delay. In addition, the preliminary feasibility investigation comprised of early developments on fields, including adits and a shaft. Early developments have ensured sufficient ore data, which considers it as a great prospective for Titanium. This factor increases stakeholder's willingness to invest, making the project more outstanding.

Additionally, the mining plan demonstrates relatively fair production rates (around 163,240 tons/year), while extending the life of mine up to 90 years. The most viable mining method suitable for this project is open-pit, with drill and blast. Though, given the circumstances at Piampaludo, this method does not abide by site laws at the moment. Therefore, following a conservative approach the project is classified with F2.2 on the F axis.

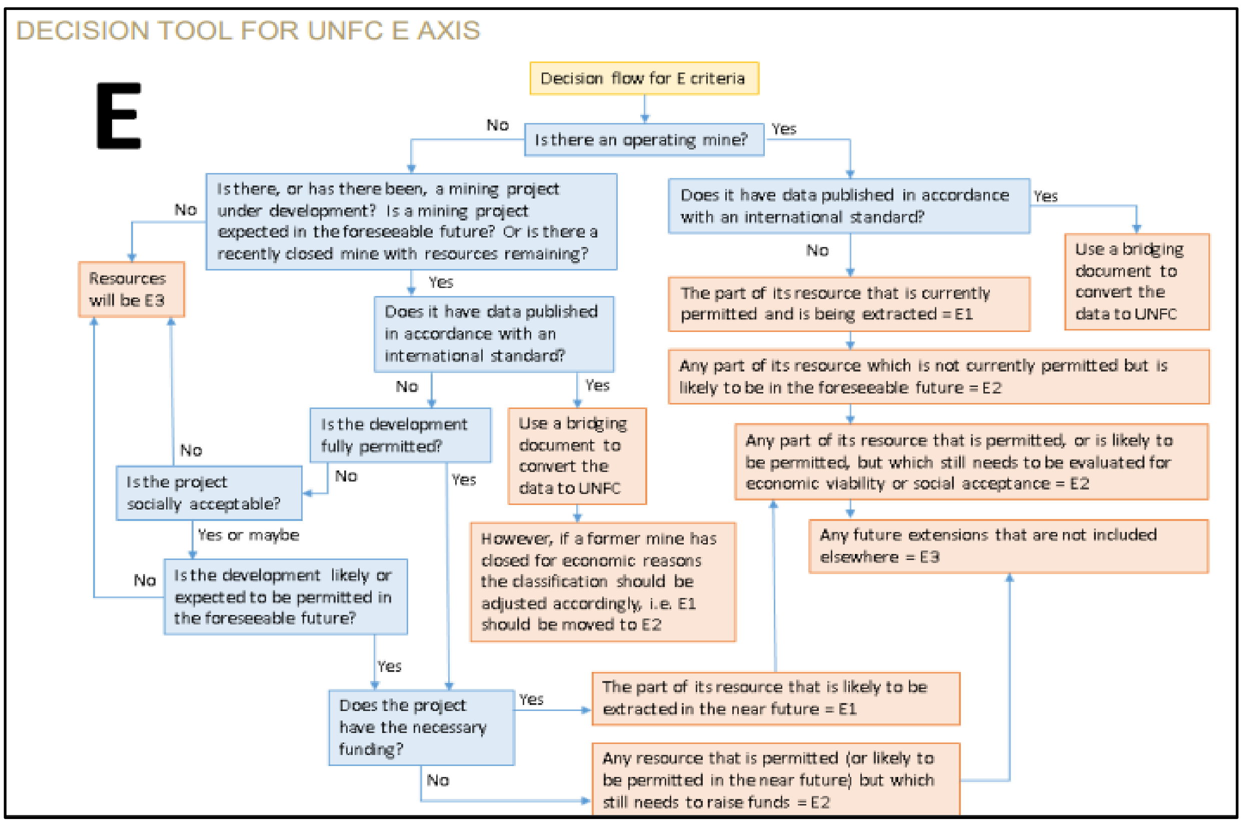
A Different Approach to Classifying Piampaludo according to UNFC

By reason of its flexibility, a wide portion of the UNFC relies on the classifier's subjectivity in decision-making, which renders some projects to be classified with ambition, others with conservation. For that reason, the British Geological Survey (BGS) has developed a set of decision flow trees as decision-making tools to objectify the UNFC classification. Accordingly, the Piampaludo project is classified following the objective tools developed by BGS in this section, and compared to the previous classification.

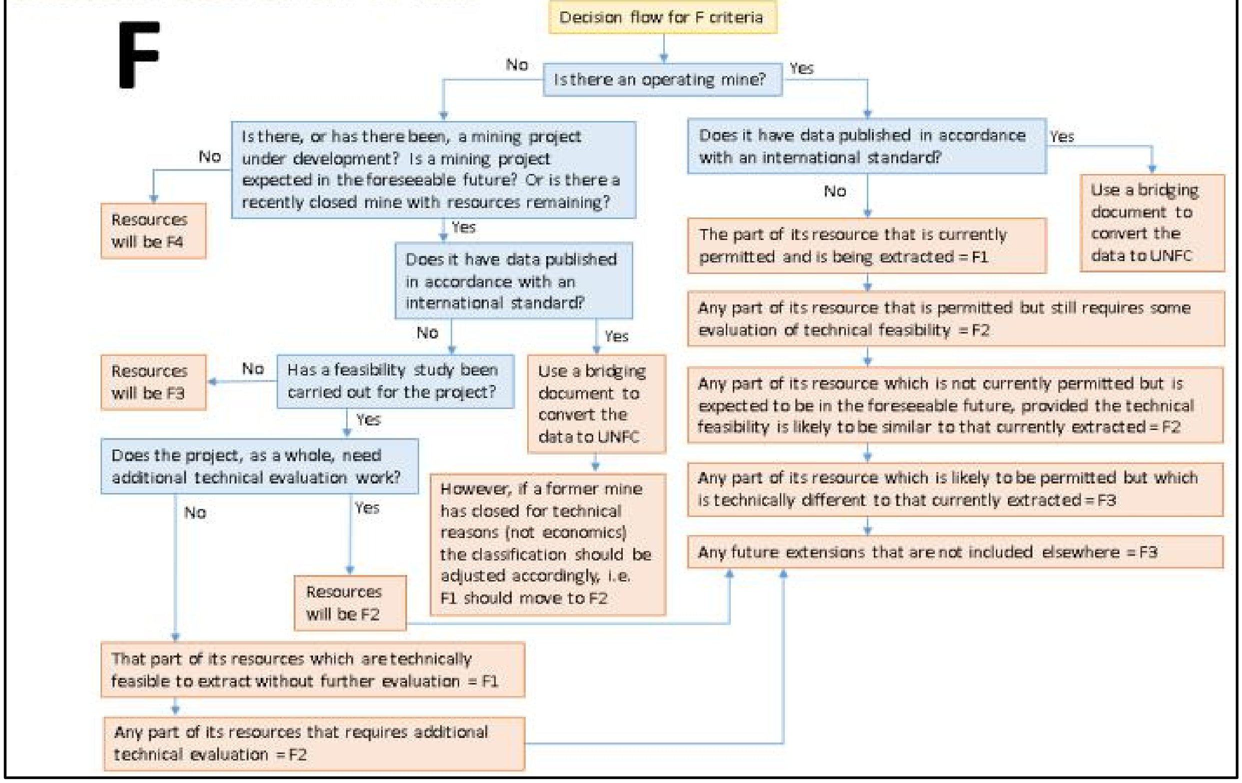
To begin with, BGS outlined the decision flow trees as a mean to facilitate the implementation of a harmonized national inventory of UK's mineral resources between the organizations, while reporting in UNFC [64]. The said UNFC-inventory aims at standardizing national mineral resource data from diverse sources, which enables the comparison among the reported data of various commodities at national, regional, and, if adopted world-wide, global levels. Ultimately, this classification paves the way to recognize obstacles facing resource developments with the required interventions for mitigation [64].

BCG developed the decision trees (Figure 19) according to the 3 axes of the UNFC, with the intention to reduce subjectivity in applying this reporting scheme. Through a process of iteration with several stakeholders, the decision flows are generated to supply basic yes or no answers of an array of common situations to define the UNFC classes. It should be noted that these tools serve solely as a guide to secure consistent UNFC reporting by field experts, they are not definite and non-experts may refer to them as an aid [64].

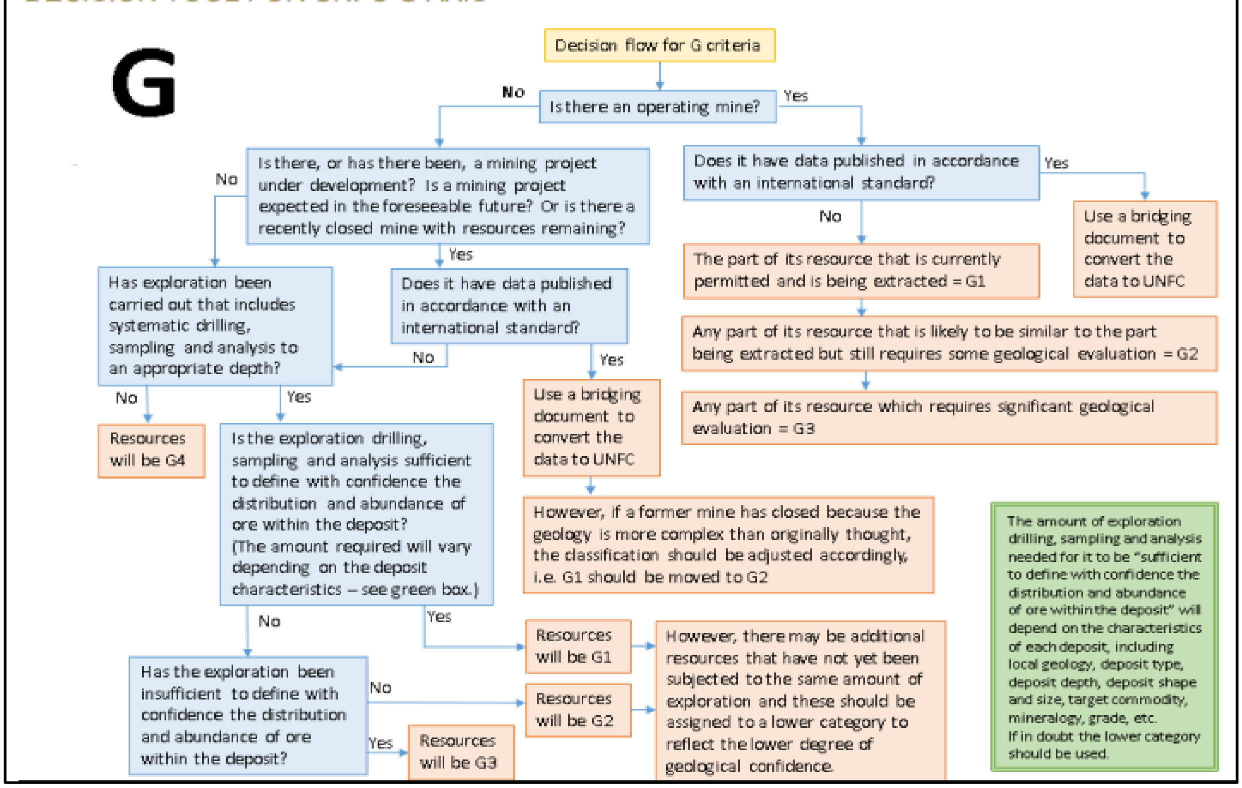
Figure 19: Decision-Trees for Determining UNFC Classes by BGS [64]



DECISION TOOL FOR UNFC F AXIS



DECISION TOOL FOR UNFC G AXIS



The Piampaludo project was classified as E2F2.2G2+G3 according to the conventional way of approaching UNFC. The following shows how BGS's decision trees were used for the classification of the Piampaludo project:

- E Axis: To begin with, the Piampaludo project has no operating mine. According to recent events, a mining project can be expected in the foreseeable future, yet no data have been published with respect to a recognized standard. Following the chart, the question of permit is vague at this point, since Piampaludo only holds an exploration permit. The project displays insufficient information regarding social acceptability. Despite showing on the E axis tree, one should note that project funding goes under technical feasibility, the F axis. Therefore, in accordance to the E axis decision tree, Piampaludo belongs to the E3 category.
- F Axis: This decision tree starts similarly to the E Axis, following a "no" for the presence of an operating mine, a "yes" for an expected mining project in the foreseeable future, and again a "no" for published data according to an international standard. Regarding the feasibility study, Piampaludo has carried out one, yet it still requires further technical evaluation. Thus, according to the F axis decision tree, the project conforms to the F2 category.
- G Axis: A similar start to the previous axes for the degree of confidence with no operating mine, an expected mining project, and no reported data. The Piampaludo project underwent exploration testing, including drilling, sampling, and analysis that define the ore distribution and abundance with confidence. Hence, Piampaludo's rutile is given a G1 category on the G axis decision tree. In addition, the decision tree states that in the case of other resources with limited exploration data, they should be assigned a lower category on the degree of confidence, rendering the garnet of the site at G2.

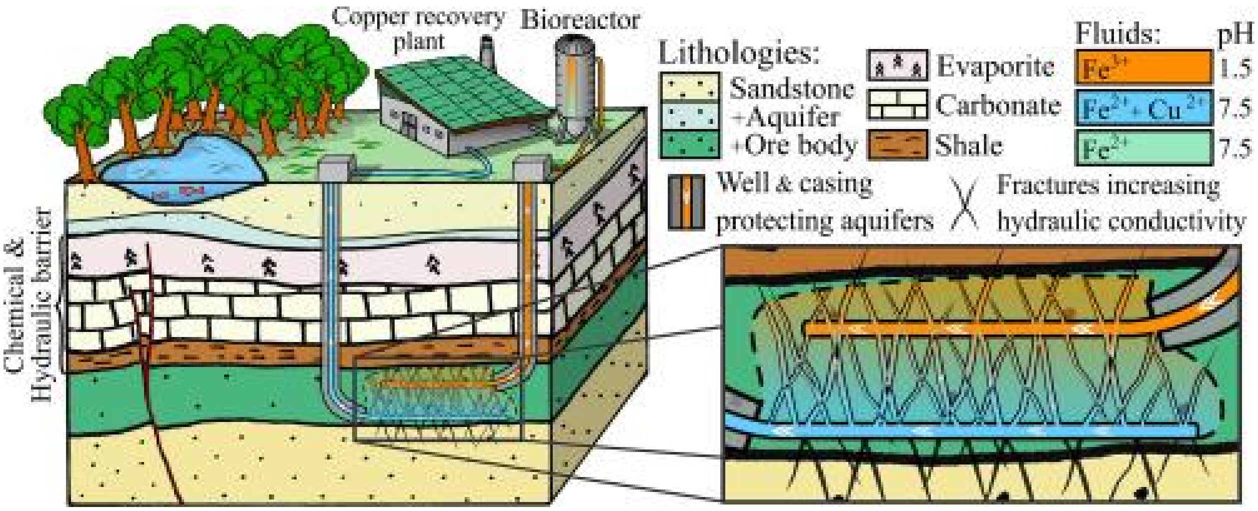
Thus, according to BGS's decision trees, the Piampaludo project is given E3F2G1+G2. The classification is obviously different from the previous classification with the conventional, subjective approach. This reflects UNFC's flexibility. However, these decision trees require further developments, as they do not incorporate the subdivisions of the categories. An additional point needing development is the matter of project funding, in which is typically considered under technical feasibility and not socio-environment-economic viability. Nevertheless, the trees serve as a useful preliminary approach to UNFC reporting.

Alternative Resource Extraction Method

The question mark tied with the Piampaludo project remains on how to recover this Titanium resource while complying with the sustainable development future. Indeed, applying conventional mining methods recovers the resource within a reasonable timeframe. As previously mentioned, the Piampaludo field is most viably exploited through the drill and blast method via open pit; however, this viability serves mostly the economic aspect and disregards other sustainable factors. Given the circumstances at this point, open pit mining of the Piampaludo field does not conform to site laws. As a result, the following paragraphs were developed to introduce possible solutions of Titanium recovery while maintaining a sustainable approach. New mining methods have become more and more innovative, clean, but mostly safer in terms of health and environment.

As a potential solution, biotechnologies have been relatively newly introduced to the mining industry as unconventional methods of extracting metals with advanced technologies, such as biomining. Biomining has evolved initially as a subsurface bioremediation technology, where metallic intrusions have contaminated the system and needed to be flushed out. This technology is basically an extraction process of metals by the interaction between minerals and microorganisms, such as bacteria. This method requires the injection of these bacteria into the medium, where they can directly or indirectly separate the ore. Yet, it is only effective on heavy metals. Going further into the process, biomining uses prokaryotes, or plants in some cases, that are capable of secreting various organic compounds that bond metals from their setting with the organic cells to coordinate electrons; this process is known as “chelation”. Biomining is an encouraged technology for the recovery of critical metals. The extraction process undergoes mining and processing simultaneously, as it dissolute the metal from its source by means of bioactivities which allow the metallic element to be extracted by a filtering process [65]. This method is built on a chain of biochemical reactions. In simple terms, it transforms insoluble metallic compounds into ions, in liquid solutions (Figure 20). The process of in situ biomining requires initially pumping a solution rich in microorganisms into the ore-bearing rock formation, which percolates the medium and reacts with the metals to dissolve them. The solution is then extracted from a different well, after being completely saturated with the metallic ions. The metal-rich solution is collected and processed to obtain the raw metal, whereas the remnant microbial solution is re-pumped to repeat the continuous process.

Figure 20: In Situ Biomining Concept Model [66]



The implementation of biotechnology in the mining industry is still under testing, meaning that, because it's relatively a new method, it is not commonly adopted for mining e.g. less than 5% of mining activities worldwide apply biomining. However, its application provides many environmental, social, and economic advantages.

From an environmental point of view, in situ biomining does not require physical removal of the rocks, which means that only minor disruption of the geodiversity occurs. This is ideal in the context of the Piampaludo field, as it is located in a Geo-Park, where the rock lithology is protected. In effect, biomining is considered more environmentally friendly compared to conventional mining methods, mostly because this technique discharges only substances from bacterial activities, such as metabolites. In addition, volumes associated with in situ biomining are lesser, resulting in the reduction of surface, water, and air pollution risk. Consequently, this method can come about in occupied areas and in various climate conditions. A main environmental concern connected to this method is the risk of losing the injected solution into surrounding soils and waters that may taint the medium. However, with appropriate planning and operations, this matter can be minimized.

In situ biomining can be used as a remediation method, meaning that the injected bacteria-rich solution is capable of cleaning toxic substances, such as oils, radioactive compounds, and sulphate toxins, present in the ecosystem. As a result, the biodiversity is subjected to protection in addition to the surrounding communities. Moreover, unlike conventional mining, this technique eludes the emissions of sulfur dioxide, which are poisonous, harmful to the environment, and creates health problems to miners. Certainly, the Piampaludo site may witness less social opposition with in situ biomining compared to any other mining method.

Economically, this method provides significant savings. Since in situ biomining incorporates both extraction and processing activities, development costs as well as transportation expenses are significantly reduced. In fact, this technique is more cost-efficient compared to typical smelting processing methods. This goes alongside with infrastructure and energy cuts. As a result, the project has the potential to initiate with low capital investments with increasing production rates. It is noteworthy to mention that this method has control over production capacities, which allows flexibility of productions with respect to stock prices.

The aforementioned biotechnology could be a possible method for Titanium recovery of the Piampaludo site deposits. With the given factors, this technique ranks the project at better socio-environmental-economic viability categories according to UNFC. However, one must take into account the precautionary principle when adopting in situ biomining. This method remains on testing scales and the circumstances of introducing new substances to an active ecosystem are yet to be further investigated in order to avoid bigger hazards. An alternative could be found in making use of the existing microorganisms of the system, where the injected substances act as catalyzers to enhance and accelerate microbial activities; thus biomining. This renders the project to E3F3G2 categories according to UNFC, since it stands as a conceptual plan and no developments have taken place.

Biotechnology; a Nature-based Solution

The application of biotechnology as a resource recovery method at the Piampaludo field can be thought off as a mean to promote the biodiversity in place. By introducing the appropriate injects (for example the correct pH) in the medium; the microbial activity can be enhanced and accelerated which allows the recovery of the Titanium present, through the same process of biomining, while enriching the microbial biome. This process minimizes the risks associated with the precautionary principle, since it only enriches the available microbes. Subsequently, other living organisms in the ecosystem suffer no harm, and may benefit from the increase of microorganisms in the case of a symbiotic relation. Furthermore, with the enhancement of the biodiversity as well as the recovery of the resource, the Piampaludo project becomes a nature-based solution. As previously stated, ameliorating microbial living standards supports the biodiversity and wildlife. Microorganisms are vital for a healthy biome and a vigorous immune system. Global biodiversity is witnessing negative impacts at increasing rates compared to historical rates, caused by the loss of microbial biodiversity, such as bacteria and fungi. This nature-based solution also supports humans. Titanium significantly benefits the health sector; it is widely used in prosthetics, heart valves, and medicine. Evidently, Titanium extracted from Piampaludo could save human and animal lives. Moreover, this solution supports sustainable welfare in terms of low carbon energy, economy, and solutions. Using biotechnology as a resource recovery method at Piampaludo defines the extraction of this Titanium resource as a service to humans, biodiversity, wildlife, and the environment.

Routing the Piampaludo field deposits towards a nature-based project to use the resource as a service requires an inclusive resource management system that guarantees responsible governance over the entire life cycle. The Piampaludo project can be best developed and managed by the United Nations Resource Management System (UNRMS). A pilot study of the application of UNRMS should be the most appropriate way forward for the Piampaludo project to demonstrate the alternatives for developing the project in a socially, environmentally, and economically viable manner.

UNRMS is a comprehensive system developed to sustainably manage resources while providing a set of principles oriented towards the 2030 Agenda. UNRMS principles align appropriately with the Piampaludo project, as it reasonably complements the requirements for a sustainable resource project and is an extension of the UNFC. UNRMS is also a principles-based framework that responds to all challenges facing a resource while considering the dynamic time and space factors impacting the society and the environment; it provides principles, specifications, and guidelines to establish the project's fundamentals. The methodology adapted within UNRMS incorporates circularity, transparency, innovation, health and safety, society, the planet, government, and many more that steer decision-making towards attaining the SDGs, guaranteeing social and environmental well-being. This comprehensive resource management system is built to assist all stakeholders, including governments, investors, and the public, sustainably pursuing their goals.

UNRMS is needed for the Piampaludo project; it offers a logical approach to the social and environmental complexities linked to the project, transforming the recovery of the Titanium in the field as a public good. Adapting this system increases the chances of social acceptance, leading to the development of this project in a sustainable matter while attracting the necessary investments. In effect, the classification of Piampaludo's Titanium deposits according to UNFC is a direct approach aligned with the Sustainable Development Goals. UNFC provided an assessment of the quantities of Titanium and the maturity status of the project as a whole. The information associated with the UNFC-data gave a complete understanding of Piampaludo's constraints and opportunities.

Simultaneously, UNRMS can serve as a toolkit to develop the Piampaludo project over its lifecycle while complementing the UNFC-data. To elaborate further, UNRMS strips down the project to find alternatives to dissolve its issues by creating innovative and rational solutions, e.g. introducing biotechnologies to recover the Titanium deposits while assuring social and environmental well-being. As a result, the project anchors on the UNRMS principles to reach the necessary social, environmental, and economic objectives. UNFC and UNRMS go hand in hand; UNFC provides information on the project's maturity, while UNRMS works toward improving the project's maturity.

Figure 21: UNRMS link to UNFC and Project-level Application [67]

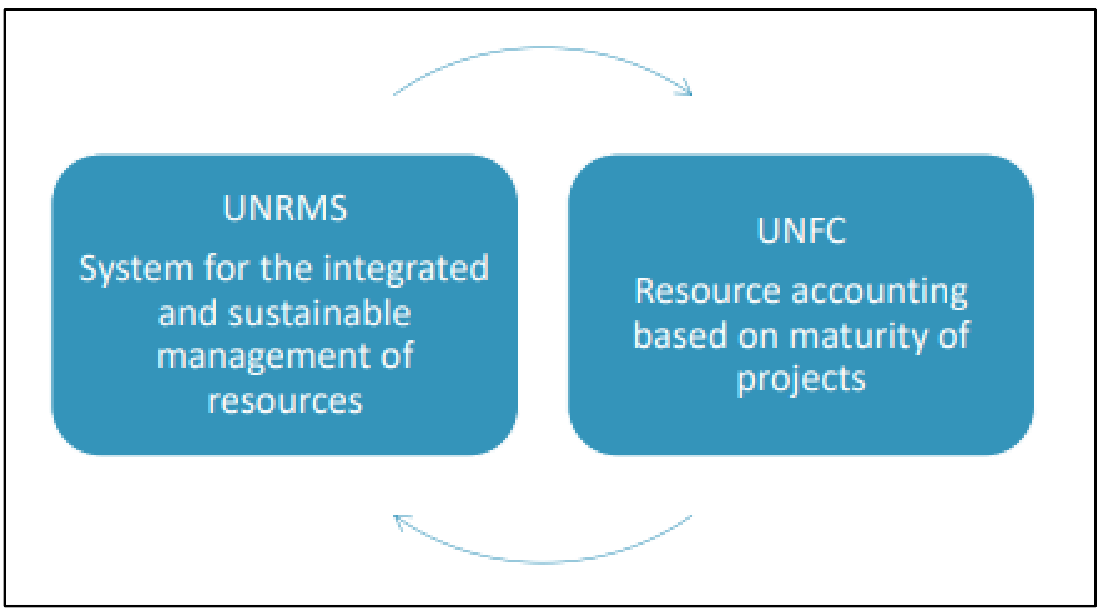


Figure 22: UNFC and UNRMS Interchange [67]

UNFC	UNRMS
Stewardship of an asset A tool for quantifying the volumes produced, recoverable and unrecoverable from all possible projects in a source (note that in application to renewable energy UNFC quantifies the volumes associated with a single project) A point in time view under defined commercial conditions, opportunities and constraints	Development of a project, which is an integral piece in the sustainable development programme An aid to decision-makers measuring the actual progress of a project through the development stages and programme managers on how it contributes to sustainable development Project management considering all metrics to the decision-makers including volume/quantities from UNFC, rate profile, economic indicators, environmental performance, social outcomes The toolkit for implementation, analysis and governance at the project level

Conclusion and Recommendations

Fast growth rates of the global population put the mining sector, as well as the energy industry, in a difficult position. Mineral supply has now to increase more than ever. At the same time, the notion of sustainable development is crucial to uphold or better yet improve the well-being of the present and future generations. The emerging question is on how to properly manage resources with respect to a social, environmental, and economic development of the necessary energy that backs-up a desirable sustainable future. To this end, securing resources commences with a comprehensive mapping of supply and demand through the management of energy and raw materials in sustainable framework.

The mining industry plays an active role in achieving SDGs. With the adequate management tools, this industry has the potential to secure a sufficient and affordable supply of raw materials. Hence, UNFC was developed to provide information in alignment with the 2030 Agenda to help solve this issue while ticking off the SDGs. UNFC is a universally accepted tool for resource assessment. It is a principles-based classification system that evaluates resource projects according to 3 fundamental pillars: environmental-socio-economic viability (E), technical feasibility (F), and degree of confidence in the estimate (G). UNFC's competitive advantage is that it works with all energy resources such as oil and gas, renewables, nuclear, CO_2 injection projects, groundwater, minerals, and anthropogenic resources. UNFC provides guidelines to enhance resources management and their development while considering social and environmental factors and the economy. These points are highly stressed on within the UNFC, on the short and long run. UNFC is therefore required to attain information regarding the SDGs; it directly impacts responsible production, consumption of resources, etc.

The Titanium deposits of the Piampaludo field in Liguria, Italy have been identified as one of the largest deposits in Europe and worldwide. The potential productions this site offers are beyond sufficient. Economically, the Piampaludo ore, with the estimated grades and weights, has the competency to significantly support the supply of Titanium across Europe. In addition, may add to the Italian mining sector which could impact not only the Ligurian economy, but the national GDP to some degree. The interest of this field has escalated in 2020, ever since the European Commission recognized Titanium as a Critical Raw Material. This means that Europe faces a decrease in Titanium supply, and is forced to carry on with external dependency for the supply of this commodity, unless regional extraction multiplies.

On the other hand, the Piampaludo site is partially located, about 50% of its total area, in a natural park, the Beigua Regional Natural Park. This raises several controversies regarding the extraction of the Titanium in this field. The issue is mostly tied with social and environmental contingencies that impede the Piampaludo project to move forward. From a social point of view, local and neighboring communities oppose the project due to the fact that mining this field is at high risk of disturbing the natural setting of the park. The park is labeled as a Geo-Park by UNESCO, and its geological features, including rocks and fossils, are protected by park authorities in order to preserve the geologic history as part of safeguarding the natural heritage unveiled by the Beigua Geo-Park. In addition, the area houses historical and archeologic artifacts that need to be preserved. From an environmental point of view, the Beigua Natural Park is characterized by its rich biodiversity, from fauna and flora to microorganisms. Environmental associations have disregarded the acceptance of mining in this field as it might cause harm to the biodiversity. In fact, the Beigua Park is part of the Natura 2000.

For that purpose, the Piampaludo field is a subject of interest. UNFC was applied to this project to highlight the issues related to it. The classification is done in consideration of social, environmental and economic factors, including the technical status and the quantities of the ore. Despite the challenges facing Piampaludo's Titanium deposit, the classification according to UNFC addresses them in a sustainable matter. One should note that UNFC is a tool that informs stakeholders on the current status of the project.

The geology of this field has been the subject of several studies over the years. Extensive research, including drilling, coring, mapping, geophysical and chemical testing, has strengthened the level of knowledge for estimating the grade, quantity, and weight of Titanium, as well as less knowledge about garnet, as a secondary mineral. Moreover, Piampaludo field was a prospect projects and has been subjected to exploration studies and preliminary developments. As a result, the degree of confidence in these estimates is ranked high for the Titanium, and partial for the garnet. Thus, the Piampaludo project was given a G2+G3 classification on the G axis, following a conservative approach.

The environmental-socio-economic viability of the Piampaludo project is controversial. Although the project has been opposed over the years, the project holder, C.E.T srl, has been recently granted exploration rights by the court. One can only assume that the explorations will lead to further investigation, such as EIA and SEA. Furthermore, being part of the Natura 2000 does not necessarily mean that the field is untouchable, the EC proposed methods of excavating in these areas. With that being said, the development of Piampaludo is not certain to be environmentally-socially-economically viable due to insufficient information to impede the project. Thus, the current circumstances of the project classify it under E2 on the E axis.

Preliminary planning was held at Piampaludo that include prefeasibility and scoping studies. These studies provide enough data on the possibility of advanced developments with a clear resource definition, giving it a more advanced category on technical feasibility. Given that the preliminary feasibility investigation comprised of early developments on fields, including adits and a shaft, the project is classified with F2.2 on the F axis. However, more studies are yet needed to be in accord with the technical feasibility of the project.

The classification of Piampaludo's Titanium deposits according to UNFC is a direct approach aligned with the Sustainable Development Goals. UNFC provided an assessment of the quantities of Titanium and the maturity status of the project as a whole. The information associated with the UNFC-data gave a complete understanding of Piampaludo's constraints and opportunities. With that in mind, a solution is needed to allow the recovery of this resource while abiding to a sustainable development. The introduction of biotechnologies, biomining may be a potential way out. With minimal harm to the natural landscape and geology, this method recovers the metal through the use of microorganisms. It is certainly more environmentally friendly than conventional mining methods. Biomining could enhance microbial life in the ecosystem, which is closely tied with improving the wider biosphere of the area. Thus, the project could be observed and developed as a nature-based solution, using the resource as a service. This ideology falls under the umbrella of UNRMS. This said resource management system provides principles and rules that allow the resource of the field to be extracted with sustainable means. Using the existing microbes of the medium while enhancing their activities accelerates the production of the metal commodity. UNRMS is essential for the Piampaludo project because it builds on logical methods to face social and environmental complexities linked to the project, allowing the recovery of the Titanium in this field to be considered as a public good. With this approach, all stakeholders become more accepting to the idea of developing the project. For that purpose, the Piampaludo project would make a great case study for the application of UNRMS.

UNFC and UNRMS go hand in hand; the UNFC provides information on the project's maturity, while the UNRMS works toward improving the project's maturity. This case study underscores the need for UNFC. However, this is insufficient on national and regional scales. The Italian resource management sector is recommended to apply the UNFC across all their mineral commodities, which shall lead to a comprehensive inventory that provides a complete picture of the sector and the way forward. Using the UNFC informs mining companies and other energy organizations in Italy about other resource projects while facilitating decision-making. In the context of the Piampaludo project, stakeholders now have sufficient information on the resource, making them aware of the project’s potential development. In addition, UNFC is apt with all energy resources, which opens the gate for investors to acquire interest not only in mineral commodities. The application of the UNFC for Italian resources shall enhance the national as well as the regional energy sector. With further developments, the projects classified under the UNFC can be subject to appropriate improvements with the implementation of UNRMS.

The application of UNFC to Piampaludo project aims at increasing the interest of this project, with hopes of proceeding with its production. This matter can be foreseen with the appropriate adaption of UNRMS in order to serve all stakeholders. In addition, this case study intends to act as an initial step forward for the introduction of UNFC into Italian realms and enhance the relation between Italian member state and EGRM in order to get proper consultation and advisory on UNFC and UNRMS. The way forward includes the development of a dataset for Italian mineral resources classified according to UNFC that represents all mineral resources of Italy in a consistent, coherent, and harmonized process. This dataset shall take into account the authorizations, technical feasibility, geology, and environmental-socio-economic aspects of the occurrences in order to provide a complete picture of Italian commodities, specifically on potential critical raw materials and their potential supply from and to regional sources in the future.

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ANNEX 1

DEFINITION OF UNFC CATEGORIES AND SUB-CATERGORIES

E Axis – Environmental-Socio-Economic Viability

Category	Definition	Supporting Explanation
E1	Development and operation are confirmed to be environmentally-socially-economically viable.	Development and operation are environmentally-socially-economically viable on the basis of current conditions and realistic assumptions of future conditions. All necessary conditions have been met (including relevant permitting and contracts) or there are reasonable expectations that all necessary conditions will be met within a reasonable timeframe and there are no impediments to the delivery of the product to the user or market. Environmental-socio-economic viability is not affected by short-term adverse conditions provided that longer-term forecasts remain positive.
E2	Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future.	Development and operation are not yet confirmed to be environmentally-socially-economically viable but, on the basis of realistic assumptions of future conditions, there are reasonable prospects for environmental-socio-economic viability in the foreseeable future.
E3	Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early a stage to determine environmental-socio-economic viability.	On the basis of realistic assumptions of future conditions, it is currently considered that there are not reasonable prospects for environmental-socio-economic viability in the foreseeable future; or, environmental-socio-economic viability cannot yet be determined due to insufficient information. Also included are estimates associated with projects that are forecast to be developed, but which will be unused or consumed in operations.

F Axis – Technical Feasibility and Maturity

Category	Definition	Supporting Explanation
F1	Technical feasibility of a development project has been confirmed.	Development or operation is currently taking place or, sufficiently detailed studies have been completed to demonstrate the technical feasibility of development and operation. A commitment to develop should have been or will be forthcoming from all parties associated with the project, including governments.
F2	Technical feasibility of a development project is subject to further evaluation.	Preliminary studies of a defined project provide sufficient evidence of the potential for development and that further study is warranted. Further data acquisition and/or studies may be required to confirm the feasibility of development.
F3	Technical feasibility of a development project cannot be evaluated due to limited data.	Very preliminary studies of a project, indicate the need for further data acquisition or study in order to evaluate the potential feasibility of development.
F4	No development project has been identified.	Remaining quantities of product not developed by any project. These are quantities which, if produced, could be bought, sold or used (i.e. electricity, heat, etc., not wind, solar irradiation, etc.).

G Axis – Degree of Confidence

Category	Definition	Supporting Explanation
G1	Product quantity associated with a project that can be estimated with a high level of confidence.	Product quantity estimates may be categorized discretely as G1, G2 and/or G3 (along with the appropriate E and F Categories), based on the degree of confidence in the estimates (high, moderate and low confidence, respectively) based on direct evidence. Alternatively, product quantity estimates may be categorized as a range of uncertainty as reflected by either (i) three specific deterministic scenarios (low, best and high cases) or (ii) a probabilistic analysis from which three outcomes (P90, P50 and P10)[3] are selected. In both methodologies (the "scenario" and "probabilistic" approaches), the estimates are then classified on the G Axis as G1, G1+G2 and G1+G2+G3 respectively. In all cases, the product quantity estimates are those associated with a project. Additional Comments: The G axis Categories are intended to reflect all significant uncertainties (e.g. source uncertainty, geologic uncertainty, facility efficiency uncertainty, etc.) impacting the estimate forecast for the project. Uncertainties include variability, intermittency and the efficiency of the development and operation (where relevant). Typically, the various uncertainties will combine to provide a full range of outcomes. In such cases, categorization should reflect three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3.
G2	Product quantity associated with a project that can be estimated with a moderate level of confidence.	
G3	Product quantity associated with a project that can be estimated with a low level of confidence.	
G4	Product quantity associated with a Prospective Project, estimated primarily on indirect evidence.	A Prospective Project is one where the existence of a developable product is based primarily on indirect evidence and has not yet been confirmed. Further data acquisition and evaluation would be required for confirmation. Where a single estimate is provided, it should be the expected outcome but, where possible, a full range of uncertainty should be calculated for the prospective project. In addition, it is recommended that the chance of success (probability) that the prospective project will progress to a Viable Project is assessed and documented.

Category	Sub-Category	Sub-Category Definition
E1	E1.1	Development is environmentally-socially-economically viable on the basis of current conditions and realistic assumptions of future conditions.
	E1.2	Development is not environmentally-socially-economically viable on the basis of current conditions and realistic assumptions of future conditions, but is made viable through government subsidies and/or other considerations.
E2	No Sub-categories defined	
E3	E3.1	Estimate of product that is forecast to be developed, but which will be unused or consumed in operations.
	E3.2	Environmental-socio-economic viability cannot yet be determined due to insufficient information.
	E3.3	On the basis of realistic assumptions of future conditions, it is currently considered that there are not reasonable prospects for environmental-socio-economic viability in the foreseeable future.

Category	Sub-Category	Sub-Category Definition
F1	F1.1	Production is currently taking place.
	F1.2	Capital funds have been committed and implementation of the development is underway.
	F1.3	Studies have been completed to demonstrate the technical feasibility of development and operation. There shall be a reasonable expectation that all necessary approvals/contracts for the project to proceed to development will be forthcoming
F2	F2.1	Project activities are ongoing to justify development in the foreseeable future.
	F2.2	Project activities are on hold and/or where justification as a development may be subject to significant delay.
	F2.3	There are no plans to develop or to acquire additional data at the current time due to limited potential.

Category	Sub-Category	Sub-Category Definition
F3	F3.1	Site-specific studies have identified a potential development with sufficient confidence to warrant further testing.
	F3.2	Local studies indicate the potential for development in a specific area but requires more data acquisition and/or evaluation in order to have sufficient confidence to warrant further testing.
	F3.3	At the earliest stage of studies, where favourable conditions for the potential development in an area may be inferred from regional studies.
F4	F4.1	The technology necessary is under active development, following successful pilot studies, but has yet to be demonstrated to be technically feasible for this project.
	F4.2	The technology necessary is being researched, but no successful pilot studies have yet been completed.
	F4.3	The technology is not currently under research or development.

G – Degree of Confidence

Category	Sub-Category	Sub-Category Definition
G4	G4.1	Low estimate of the quantities.
	G4.2	Incremental amount to G4.1 such that G4.1+G4.2 equates to a best estimate of the quantities.
	G4.3	Incremental amount to G4.1+G4.2 such that G4.1+G4.2+G4.3 equates to a high estimate of the quantities.

ANNEX 2

GLOSSARY OF TERMS FOR MINERAL PROJECTS

MINERALS TERMS	
Terms	**Definition**
Minerals Source	A Minerals Source is a concentration or occurrence of material quantity of intrinsic commercial or Political interest, in such form, quality and quantity from which a benefit is produced.
Minerals Life Cycle	The Minerals Life Cycle usually starts with the exploration and subsequent primary mineral production in the course of a mining operation, and decommissioning and site remediation. This step reflects the primary entrance of raw materials into the stock available for economic value chains. During the length of stay within value-added chains, the mineral nature and compositions might be multiply altered in linear and cyclic processes (recycling).
Potential (Minerals) Source	A Minerals Source that has not yet been demonstrated to exist by direct evidence but is assessed as potentially existing based primarily on indirect evidence or evidence with limited density of exploration data.
Product (Minerals)	Products of the project may be bought, sold or used. In some cases the product and the source are similar and might be utilized directly (e.g., aggregates); in other cases the product is indirectly utilized i.e. derived from the source by industrial processes like beneficiation (steel / iron from iron ore).
Prospective Project	A Project that is associated with one or more Potential Minerals Source (See Potential Source). The results of a prospective project might potentially provide the necessary direct evidence for a Known Minerals Resource.
Remediation (or Reclamation)	**T**he restoration of a project site conditions that are required by regulatory or other provisions.
Reasonable Expectations	High level of confidence. This term is used within the E1 classification and concerns the likelihood that all necessary conditions will be met. It is also used in the F1.3 Sub-category and concerns the likelihood that all necessary approvals/contracts for the project to proceed to development will be forthcoming.
Reasonable Prospects	Moderate level of confidence. This term is used within the E2 and E3 classification and concerns the likelihood that all necessary conditions will be met.
Reasonable Time Frame	The time frame within which all approvals, permits and contracts necessary to implement the project are to be obtained. This should be the time generally accepted as the typical period required to complete the task or activity under normal or typical circumstances.
Viable	A project is viable when it has been confirmed to be economically, socially, technically and environmentally feasible and satisfies all the relevant criteria of the E, F, and G axes that are required for it to proceed.

ANNEX 3

OVERVIEW OF ITALIAN LEGISLATIONS ON EXPLORATION AND EXTRACTION ACTIVITIES

Legislative Sector: mining, minerals management, technical safety, concession:

Code	English title	Web link	Permitting provisions (Y/N)	Deadlines (Y/N)	Relevant to (Y/N)			Relevant at (Y/N)		
					exploration	extraction	post-extraction	local	regional	(central) national
IT-L1	Emilia-Romagna Regional Law 18 July 1991, n. 17: rules on mining activities	http://demetra.regione.emilia-romagna.it/al/monitor.php?vi=nor&dl=d2f25821-92ae-032f-d36b-4e4cbfc0e7b9&dl_id=10&dl_t=xml&dl_a=y&ev=0	Y	Y	Y	Y	Y	Y	Y	N/A
IT-L2	Royal decree 29/07/1930	http://ambiente.regione.emilia-romagna.it/suolo-bacino/argomenti/attivita-estrattive-e-minerarie/allegati/regio-decreto-29-luglio-1927-n.1443	Y	Y	Y	Y	Y	N	Y	Y
IT-L3	L30/91 Rules for the execution of mineral policy	http://www.ambientediritto.it/Legislazione/CAVE/Legge%20n.221-1990.htm	N	N	Y	Y	Y	N	Y	N/A
IT-L4	Decree 117/2008 Law on Mineral waste	http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legislativo:2008-05-30;117%21vig=	N	N	N	Y	Y	Y	Y	Y
IT-L5	Decree 626/94: Safety during working activities	https://it.wikipedia.org/wiki/Decreto_legislativo_19_settembre_1994,_n._626	N	N	Y	Y	Y	Y	Y	Y
IT-L6	Decree 624/96: Rules for safety in mining activities	http://www.sicurcave.it/PDF/624DLv96.pdf	N	N	Y	Y	Y	Y	Y	Y
IT-L7	Decree 81/2008: Safety and health during working activities	http://www.lavoro.gov.it/sicurezzalavoro/documents/tu%2081-08%20-%20ed.%20ottobre%202013.pdf	N	N	Y	Y	Y	Y	Y	Y
IT-L8	Decree 128/59: Police rules in quarry and mining activities	http://www.normattiva.it/uri-res/N2Ls?urn:nir:presidente.repubblica:decreto:1959;128	N	N	Y	Y	N	Y	Y	Y
IT-L9	Decree 21/1979: Explosive rules for mining extraction	http://unmig.mise.gov.it/unmig/norme/miniere/dm210479.pdf	N	N	N	Y	N	Y	Y	Y
IT-L10	Constitutional Law 3/2001: passing of competence on mining from State to Regions	http://www.parlamento.it/parlam/leggi/01003lc.htm	N	N	Y	Y	Y	Y	Y	Y

Code	English title	Web link	Permitting provisions (Y/N)	Deadlines (Y/N)	Relevant to (Y/N)			Relevant at (Y/N)		
					exploration	extraction	post-extraction	local	regional	(central) national
IT-L11	Piemonte Regional Law69/78 Quarry activities	http://arianna.consiglioregionale.piemonte.it/base/coord/c1978069.html	Y	Y	Y	Y	Y	Y	Y	N/A
IT-L12	Lombardia Regional Law1 4/1998 – rules on cultivation of minerals on quarries	http://www.reti.regione.lombardia.it/shared/ccurl/757/302/1998%20-%20lr%2014.pdf	Y	Y	Y	Y	Y	Y	Y	N/A
IT-L13	Veneto Regional Law 44/1982: rules on quarry activity	http://www.consiglioveneto.it/crvportal/leggi/1982/82lr0044.html	Y	Y	Y	Y	Y	Y	Y	N/A
IT-L14	Lazio Regional Law 17/2004 – Rules on quarry activities	http://notes.regione.lazio.it/RegioneLazio/Leggi.nsf/Ricconsiglio/24790E0D14E611B5C1256F4E00405016	Y	Y	Y	Y	Y	Y	Y	N/A
IT-L15	Puglia Regional Law 21/2004 – Rules on extraction activity	http://93.63.84.69/ecologia/Documenti/GestioneDocumentale/Legislazione/Attivita_Estrattive/AE_LEX_RP_06_LR21_04.pdf	Y	Y	Y	Y	Y	Y	Y	N/A
IT-L16	Provincia Autonoma di Trento Law 7/2006 – Rules on mining activities	http://www.consiglio.provincia.tn.it/leggi-e-archivi/codice-provinciale/archivio/Pages/Legge%20provinciale%2024%20ottobre%202006,%20n.%207_15798.aspx	Y	Y	Y	Y	Y	Y	N/A	N/A
IT-L17	Provincia autonoma di Bolzano Law 10/2009 – Rules on mining activities	http://lexbrowser.provincia.bz.it/doc/20150821/it/lp-2003-7/legge_provinciale19_maggio_2003_n_7.aspx	Y	Y	Y	Y	Y	Y	N/A	N/A
IT-L18	Friuli Venezia Giulia Regional Law 35/86 – Rules on mining activities	https://lexview-int.regione.fvg.it/FontiNormative/xml/xmllex.aspx?anno=1986&legge=35	Y	Y	Y	Y	Y	Y	Y	N/A
IT-L19	Liguria Regional Law 12/2012 – Rules on mining activities	http://lrv.regione.liguria.it/liguriass_prod/class/download.php?urndoc=urn:nir:regione.liguria:legge:2015-03-06;6&dcrev=ba8b7620-509f-90d2-2226-5512866cfde8&ext=P_PDF01	Y	Y	Y	Y	Y	Y	Y	N/A
IT-L20	Tuscany Regional Law 35/2015 – Rules on mining activities	http://raccoltanormativa.consiglio.regione.toscana.it/articolo?urndoc=urn:nir:re	Y	Y	Y	Y	Y	Y	Y	Y

Legislative Sector: environment:

Code	English title	Web link	Permitting provisions (Y/N)	Deadlines (Y/N)	Relevant to (Y/N)			Relevant at (Y/N)		
					exploration	extraction	post-extraction	local	regional	(central) national
IT-L31	National Decree 152/06 on Environment	http://www.camera.it/parlam/leggi/deleghe/06152dl.htm	Y	Y	N	Y	N	Y	Y	Y
IT-L32	Piemonte Regional Law 40/1998 – Rules on environmental compatibility and evaluation procedures	http://arianna.consiglioregionale.piemonte.it/ariaint/TESTO?LAYOUT=PRESENTAZIONE&TIPODOC=LEGGI&LEGGE=40&LEGGEANNO=1998	Y	Y	N	Y	N	Y	Y	N/A
IT-L33	Lombardia Regional Law 5/2010 – Rules on EIA	http://www.reti.regione.lombardia.it/shared/ccurl/5/44/lr%205_2010.pdf	Y	Y	N	Y	N	Y	Y	N/A
IT-L34	Veneto Regional Law 4/2016 – Rules on EIA and competences on Integrated environmental authorisation	https://rdv.app.box.com/s/4h5cmazi7bxuhid2tqf3md51tzscppye	Y	Y	N	Y	N	Y	Y	N/A
IT-L35	Puglia Region Deliberation	http://www.arpa.puglia.it/c/document_library/get_file?uuid=c0a9204f-bf94-4a50-8321-aa4de124cbd7&groupId=13879	Y	Y	N	Y	N	Y	Y	N/A

Legislative Sector: nature conservation, forestry:

Code	English title	Web link	Permitting provisions (Y/N)	Deadlines (Y/N)	Relevant to (Y/N)			Relevant at (Y/N)		
					exploration	extraction	post-extraction	local	regional	(central) national
IT-L36	Regional law 24/2011: Institution of regional parks	http://demetra.regione.emilia-romagna.it/al/monitor.php?vi=all&dl=7f87c1eb-3e15-bab0-e671-4efaf5a8bef4&dl_id=10&dl_t=xml&dl_a=y&ev=0	N	N	Y	Y	Y	Y	Y	N/A
IT-L37	National Law 394/91: Rules on national parks	http://www.gazzettaufficiale.it/eli/id/1991/12/13/091G0441/sg	N	N	Y	Y	Y	Y	Y	Y
IT-L38	Piemonte Regional Law 19/2009 – Protection of nature and biodiversity	http://arianna.consiglioregionale.piemonte.it/base/coord/c2009019.html	N	N	Y	Y	Y	Y	Y	N/A
IT-L39	Lombardia Regional Law 12/2011 – New regional organization on Parks, Reserves and Natural Heritages	http://normelombardia.consiglio.regione.lombardia.it/normelombardia/Accessibile/main.aspx?view=showdoc&iddoc=lr002011080400012	N	N	Y	Y	Y	Y	Y	N/A
IT-L40	Veneto Regional Law 40/1984 – Rules on Parks and Environmental Reserves	http://www.consiglioveneto.it/crvportal/leggi/1984/84lr0040.html	N	N	Y	Y	Y	Y	Y	N/A
IT-L41	Lazio Regional Law 29/1997 – Rules on individuation and institution of Parks and Environmental Reserves	http://notes.regione.lazio.it/RegioneLazio/Leggi.nsf/Ricconsiglio/CD3772636F44D28180256B790052C93D	N	N	Y	Y	Y	Y	Y	N/A
IT-L42	Puglia Regional Law 19/1997 – Rules on institution and management of Natural areas	http://www.parcootrantoleuca.it/images/stories/Legge_Regionale_19_97.pdf	N	N	Y	Y	Y	Y	Y	N/A
IT-L43	Valle d'Aosta Regional law 45/2009 – Rules on protection of Flora	http://www.regione.vda.it/risorsenaturali/conservazione/normativa/legge_flora_i.asp	N	N	Y	Y	Y	Y	Y	N/A

Code	English title	Web link	Permitting provisions (Y/N)	Deadlines (Y/N)	Relevant to (Y/N)			Relevant at (Y/N)		
					exploration	extraction	post-extraction	local	regional	(central) national
IT-L44	Provincia Autonoma di Trento law on management of environment and territory	http://www.consiglio.provincia.tn.it/leggi-e-archivi/codice-provinciale/archivio/Pages/Legge%20provinciale%2023%20maggio%202007,%20n.%2011_16530.aspx?zid=a706695c-37c3-4980-973c-9b323cdcd442	N	N	Y	Y	Y	Y	N/A	N/A
IT-L45	Provincia Autonoma di Bolazano – Law on Nature management 6/2010	http://lexbrowser.provinz.bz.it/doc/it/lp-2010-6/legge_provinciale_12_maggio_2010_n_6.aspx?q=&a=2010&n=6&in=-&na=	N	N	Y	Y	Y	Y	N/A	N/A
IT-L46	Friuli Venezia Giulia Regional Law 42/1996 – Rules on parks and reserves	http://lexview-int.regione.fvg.it/fontinormative/xml/xmlLex.aspx?anno=1996&legge=42&ART=000&AG1=00&AG2=00&fx=lex	N	N	Y	Y	Y	Y	Y	N/A
IT-L47	Liguria Region Law 12/1995 – Rules on protected areas	http://lrv.regione.liguria.it/liguriass_prod/articolo?urndoc=urn:nir:regione.liguria:legge:1995-02-22;12	N	N	Y	Y	Y	Y	Y	N/A
IT-L48	Tuscany Regional Law 30/2015 – Rules on protection and management of environment	http://raccoltanormativa.consiglio.regione.toscana.it/articolo?urndoc=urn:nir:regione.toscana:legge:2015-03-19;30	N	N	Y	Y	Y	Y	Y	N/A
IT-L49	Umbria Regional Law 9/1995 – Environment protection and reserve areas	http://www.parks.it/federparchi/leggi/umbria.html	N	N	Y	Y	Y	Y	Y	N/A
IT-L50	Marche Regional Law 15/1994 – Rules for the institution and management of protected areas	http://www.consiglio.marche.it/banche_dati_e_documentazione/leggirm/leggi/visualizza/vig/988	N	N	Y	Y	Y	Y	Y	N/A
IT-L51	Abruzzo Regional Law 38/1996 – Rules on protected areas	http://faolex.fao.org/docs/html/ita31805.htm	N	N	Y	Y	Y	Y	Y	N/A
IT-L52	Molise Regional Law 23/2004 – Management of protected areas	http://www.regione.molise.it/web/crm/lr.nsf/(Anno)/09907A1267F11076C1256F46003B33B8?OpenDocument	N	N	Y	Y	Y	Y	Y	N/A

Legislative Sector: land use planning, spatial development, soil management:

Code	English title	Web link	Permitting provisions (Y/N)	Deadlines (Y/N)	Relevant to (Y/N)			Relevant at (Y/N)		
					exploration	extraction	post-extraction	local	regional	(central) national
IT-L57	Emilia-Romagna Regional Law 20/2000: Spatial Planning	http://territorio.regione.emilia-romagna.it/codice-territorio/pianif-territoriale/legge-regionale-20-2000	N	N	Y	N	N	Y	Y	N/A
IT-L58	Piemonte Regional Law 56/77 and subsequent amendments – Spatial Planning	http://arianna.consiglioregionale.piemonte.it/base/coord/c1977056.html	N	N	Y	N	N	Y	Y	N/A
IT-L59	Lombardia Regional Law 12/2005 and subsequent amendments – Spatial Planning	http://smtp.consiglio.regione.lombardia.it/NormeLombardia/Accessibile/main.aspx?exp_coll=lr002005031100012&view=showdoc&iddoc=lr002005031100012&selnode=lr002005031100012	N	N	Y	N	N	Y	Y	N/A
IT-L60	Veneto Regional Law 11/2004 and subsequent amendments – Spatial Planning and Landscape	http://www.consigliovenet o.it/crvportal/leggi/2004/04lr0011.html	N	N	Y	N	N	Y	Y	N/A
IT-L61	Lazio Regional Law 38/1999 and subsequent amendments – Rules on territorial management	http://notes.regione.lazio.it/RegioneLazio/Leggi.nsf/RicercaIntranew/6C9F35E038B8AD8280256B790052CD39	N	N	Y	N	N	Y	Y	N/A
IT-L62	Puglia Regional Law 20/2009 and subsequent amendments – Landscape planning	http://www.paesaggio.regione.puglia.it/PPTR_2013_07/LR_20_2009.pdf	N	N	Y	N	N	Y	Y	N/A
IT-L63	Valle d'Aosta Regional Law 11/98 and subsequent amendments – Landscape planning	http://www.consiglio.vda.it/app/leggieregolamenti/dettaglio?pk_lr=2467	N	N	Y	N	N	Y	Y	N/A

Code	English title	Web link	Permitting provisions (Y/N)	Deadlines (Y/N)	Relevant to (Y/N)			Relevant at (Y/N)		
					exploration	extraction	post-extraction	local	regional	(central) national
IT-L64	Trento Province Law 1/2008 and subsequent amendments – Landscape planning	http://www.urbanistica.provincia.tn.it/normativa/legge_urb/	N	N	Y	N	N	Y	N/A	N/A
IT-L65	Bolzano Provincial Law 3/95 and subsequent amendments – Landscape planning	http://lexbrowser.provinz.bz.it/doc/it/lp-1995-3/legge_provinciale_18_gennaio_1995_n_3.aspx	N	N	Y	N	N	Y	N/S	N/S
IT-L66	Friuli Venezia Giulia President Decree 83/78 and subsequent amendments – Landscape planning	http://www.regione.fvg.it/rafvg/export/sites/default/RAFVG/ambiente-territorio/pianificazione-gestione-territorio/FOGLIA1/allegati/PURG_Adozione_DPGR_0481_05.05.1978.pdf	N	N	Y	N	N	Y	Y	N/A
IT-L67	Liguria Regional Law 36/97 subsequent amendments – Landscape planning	http://www.regione.liguria.it/component/publiccompetitions/document/1285-legge-regionale-n-36-del-4-settembre-1997-e-successive-modifiche.html?view=document&id=1285:legge-	N	N	Y	N	N	Y	Y	N/A
IT-L71	Abruzzo Regional Law 18/83 and subsequent amendments – Landscape planning	http://www.regione.abruzzo.it/xAmbiente/docs/normeMatPian/1LR18_83_Coordinato.pdf	N	N	Y	N	N	Y	Y	N/A
IT-L72	Molise Regional Law 47/85 and subsequent amendments – Landscape planning	http://www.prontogeometra.it/Molise_17_1985.pdf	N	N	Y	N	N	Y	Y	N/A
IT-L73	Campania Regional Law 16/2004 and subsequent amendments – Landscape planning	http://www.regione.campania.it/assets/documents/governoterritorio.pdf	N	N	Y	N	N	Y	Y	N/A
IT-L74	Basilicata Regional Law 23/99 and subsequent amendments – Landscape planning	http://www.regione.basilicata.it/giunta/files/docs/DOCUMENT_FILE_1921168.pdf	N	N	Y	N	N	Y	Y	N/A

<u>Legislative Sector: transportation, construction, catastrophe protection, police, military:</u>

Code	English title	Web link	Permitting provisions (Y/N)	Deadlines (Y/N)	Relevant to (Y/N)			Relevant at (Y/N)		
					exploration	extraction	post-extraction	local	regional	(central) national
IT-L79	Piemonte regional Law 1/2000 on transportation	http://arianna.consiglioregionale.piemonte.it/base/coord/c2000001.html	N	N	N	N	N	Y	Y	N/A
IT-L80	Veneto regional Law 25/1998 on local transport	http://www.consiglioveneto.it/crvportal/leggi_storico/1998/98lr0025.html?numLegge=25&annoLegge=1998&tipoLegge=Alr	N	N	N	N	N	Y	Y	N/A
IT-L81	Lazio regional Law 16/2003 on local transport	http://notes.regione.lazio.it/regionelazio/LeggiPub.nsf/0/87e7bba84c9e8062c1256d8f0041fcee?OpenDocument&Click=	N	N	N	N	N	Y	Y	N/A
IT-L82	Puglia regional Law 18/2002 on local transport	http://mobilita.regione.puglia.it/images/allegati/lr%20n18%2031_10_2002.pdf	N	N	N	N	N	Y	Y	N/A
IT-L84	Trento Provincial Law 16/1193 on local transport	http://www.consiglio.provincia.tn.it/leggi-e-archivi/codice-provinciale/archivio/Pages/Legge%20provinciale%209%20luglio%201993,%20n.%2016_973.aspx	N	N	N	N	N	Y	N/A	N/A
IT-L85	Bolzano Provincial Law 28/1991 on local transport	http://lexbrowser.provinz.bz.it/doc/it/lp-1991-28/legge_provinciale_23_ottobre_1991_n_28.aspx	N	N	N	N	N	Y	N/A	N/A
IT-L86	Friuli Venezia Giulia regional Law 23/2007 on local transport	http://lexview-int.regione.fvg.it/fontinormative/xml/xmlLex.aspx?anno=2007&legge=23&ART=000&AG1=00&AG2=00&fx=lex	N	N	N	N	N	Y	Y	N/A
IT-L87	Liguria regional Law 33/2013 on local transport	http://www.regione.liguria.it/components/com_publiccompetitions/includes/download.php?id=1442:legislazione-regionale-trasporti.pdf	N	N	N	N	N	Y	Y	N/A